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UNIVERSITY OF SOUTHAMPTON
Faculty of Physical Sciences and Engineering
Electronics and Computer Science

Routing in Intended Learning Outcome Networks

By
Teresa Binks

A thesis submitted for Doctorate of Philosophy

September 2014

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UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF PHYSICAL SCIENCES AND ENGINEERING
ELECTRONICS AND COMPUTER SCIENCE

Doctor of Philosophy

ROUTING IN INTENDED LEARNING OUTCOME NETWORKS

By Teresa Binks

This thesis explores the potential that Intended Learning Outcomes (ILOs) networks have to support learning and teaching, particularly for supporting self-directed learners. As a contribution to knowledge, this work presents evidence that suggests algorithms traversing ILO networks can produce learning routes that are similar to routes produced by teachers.

For this thesis, an ILO network comprised of cognitive learning outcomes in the area of music theory was created, and algorithms to traverse the network were designed. Trials were undertaken to determine the interpretability of the ILOs and the ILO network to non-subject matter experts. Further trials explored to what degree the routes produced by the traversal algorithms differed from routes produced by contemporary teaching professionals.

Findings indicate that ILOs and ILO networks were understood well by the learners involved in the first trial. Results from the second trial suggest that the algorithms produced similar routes to those produced by teachers, but conclude that the metrics and the route lengths may need to be refined in order to better reflect the scale of educational undertakings pursued today.

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Contents

Contents.....	iii
List of Figures.....	vii
List of Tables	xi
Acknowledgements	xviii
1. Introduction	20
1.1 Introductory Definitions	21
1.2 Motivations.....	21
1.2.1 Resource indexing	22
1.2.2 Tracking	23
1.2.3 Routing	25
1.2.4 Network Comparison	27
1.2.5 Motivation Overview.....	32
1.3 Research Aims	2
1.4 Scope.....	2
1.5 Structure	3
1.6 Summary.....	3
2. State of the Art	6
2.1 Learning and Teaching.....	6
2.1.1 Learning and eLearning.....	6
2.1.2 Teaching	7
2.1.3 The Learning Transaction.....	9
2.2 Intended Learning Outcomes (ILOs).....	12
2.2.1 Defining ILOs	12
2.2.2 The Definition of ILOs in this Work	18
2.2.3 ILO Capability Verbs	19
2.2.4 ILO Subject Matter	22
2.2.5 Structuring ILOs.....	23
2.2.6 Issues with ILOs.....	26

2.2.7	Benefits of ILOs.....	27
2.2.8	Summary.....	28
2.3	The Self-Directed Learner.....	28
2.4	Routing.....	30
2.4.1	The Teacher Sets the Route.....	30
2.4.2	Self-Directed Learners Can't Easily Route	32
2.4.3	The analogy with Minimal Guidance and Adaptive Hypermedia....	32
2.4.4	Why does order matter?.....	34
2.4.5	Summary.....	35
2.5	Similar technologies and specifications.....	36
2.5.1	Teaching Machines	36
2.5.2	Intelligent Tutoring Systems	37
2.5.3	Curricula using ILOs.....	38
2.5.4	Competencies and Competences	42
2.5.5	Learning Objects	43
2.5.6	IMS Learning Design	43
2.6	Summary	44
3.	ILO Networks and Routing Algorithms.....	46
3.1	Discussion of the State of the Art	46
3.1.1	Learning, Teaching and the Learning Transaction.....	46
3.1.2	ILOs.....	48
3.1.3	Capability Verbs and Subject Matter Types	49
3.1.4	ILO Networks and KST.....	50
3.1.5	Benefits and Drawbacks of ILOs	51
3.1.6	Self-Directed Learning and Routing	52
3.1.7	State of the Art in ILO Specifications and Systems	53
3.2	A Synthesised System.....	55
3.2.1	A Behavioural View.....	55
3.2.2	A Structural View.....	57
3.2.3	Proposed Models.....	58
3.2.4	Risks	62
3.3	Summary	63
4.	Research Question and Methodology.....	65

4.1	Research Question	65
4.2	Methodology	66
4.2.1	Experiment 1	66
4.2.2	Experiment 2	72
4.3	Summary	76
5.	Results	77
5.1	Experiment 1	77
5.1.1	Phase 1	77
5.1.2	Phase 2	79
5.1.3	Phase 3	81
5.1.4	Phase 4	83
5.2	Experiment 2	85
5.2.1	Phase 1	85
5.2.2	Phase 2	86
5.3	Summary	101
6.	Discussion of Results	103
6.1	Experiment 1	103
6.1.1	Phase 1	103
6.1.2	Phase 2	104
6.1.3	Phase 3	105
6.1.4	Phase 4	106
6.1.5	Other observations	107
6.2	Experiment 2	108
6.2.1	Phase 1	108
6.2.2	Phase 2	108
6.2.3	Limitations of Experiment 2	111
6.3	General Limitations	111
6.4	Summary	112
7.	Summary and Conclusions	114
7.1	Summary	114
7.2	Conclusions	115
7.2.1	Contributions	115

7.3 Future Work.....	116
7.3.1 More topics, More Teachers, More Algorithms	116
7.3.2 Involving Learners	116
7.3.3 Supporting software.....	116
References.....	118
Appendix A. Experiment 1 Participant Pack.....	129
Appendix B. Experiment 1 Phase 1 Data.....	145
B.1. Participant 1	145
B.2. Participant 2	145
B.3. Participant 3	146
B.4. Participant 4	146
Appendix C. Experiment 1 Phase 2 Data.....	148
Appendix D. Experiment 1 Phase 3 Data.....	153
D.1. Participant 1	153
D.2. Participant 2	153
D.3. Participant 3	154
D.4. Participant 4	155
Appendix E. Experiment 2 Participant Pack.....	157
Appendix F. Experiment 2 Phase 2 Data.....	163
F.1. Set 1	163
F.2. Set 2.....	164
Appendix G. Experiment 2 Phase 2 Graphs.....	166
Appendix H. Competences.....	168
Model of Context.....	170
Appendix I. ILO Network.....	172

List of Figures

Figure 1 Resource indexing	22
Figure 2 Unmarked ILO network.....	24
Figure 3 Marked ILO network	24
Figure 4 Routing	25
Figure 5 Exemplar network 1	28
Figure 6 Exemplar network 2	28
Figure 7 Overlapping networks (widening)	29
Figure 8 Overlapping networks (deepening)	29
Figure 9 Multiple overlapped networks.....	30
Figure 10 Overlapped networks showing resources	31
Figure 11 An overview of some of the potential utilities afforded by ILO informed systems.	2
Figure 12 Learning Transaction adapted from (Gilbert & Gale, 2007)	9
Figure 13 Learning Transaction adapted from (Gilbert & Gale, 2007), showing how each learning transaction addresses and ILO.....	10
Figure 14 HR-XML PostionCompetency ("Position Competency Model: Supporting Library Components," n.d.).....	15
Figure 15 HR-XML Competency ("Position Opening: Examples," n.d.).....	15
Figure 16 The Performance-Content Matrix (Merrill, 1983, p. 112)	22
Figure 17 Flat list of enabling outcomes for "Solve Simultaneous Equations"	24
Figure 18 Multi-level list of enabling outcomes for "Solve Simultaneous Equations" ..	24
Figure 19 Enabling ILOs for "Solve Simultaneous Equations"	24
Figure 20 Reproduced figure of "Structure on skills illustrated as Hasse diagram" (Albert et al., 2008).....	25
Figure 21 Learning Transaction adapted from (Gilbert & Gale, 2007)	31
Figure 22 An exemplar teaching machine (labelled "testing machine"), designed by Pressey and manufactured by the W.M.Welch Scientific Company. Image taken and released to public domain by Wikipedia Userq..... Gomer Bolstrood, September 2006. Background of image removed for clarity.	36
Figure 23 Extract of CS2013 Body of Knowledge for Object Orientated Programming	38
Figure 24 Adapted diagram showing mapping of an example of Reading to Content Standards and a Life Skills Competency (CASAS, 2006).....	39

Figure 25 Partial screenshot of Kahn Academy's "Knowledge Map". Accessed from https://www.khanacademy.org/exercisedashboard , 10th July 2014.	41
Figure 26 Representation showing how a competence builds upon an ILO	42
Figure 27 Elaborated roles of teaching and learning with directed learning	47
Figure 28 Elaborated roles of teaching and learning with self-directed learning	48
Figure 29 Duplication of Figure 26, showing how a Competence builds upon an ILO.	54
Figure 30 Use case diagram showing learner interactions with the ILO System. Lines labelled <<include>> show a dependence between the source and destination steps. Lines labelled <<extend>> denote conditional included steps. Lines with a hollow arrow head show an inheritance (i.e. kind-of) relation.	56
Figure 31 Structural view of a synthesised system	57
Figure 32 The definition triangle, showing three elements (name, symbol, definition) and the six pairwise associative relationships between them.	60
Figure 33 The definition triangle of "a minim" showing three elements (name, symbol, definition) and the six pairwise associative relationships between them.	61
Figure 34 Sample ILO definition shown to participants.....	67
Figure 35. Sample resource snippet sheet associated with the ILO definition shown in Figure 34. The expected match is option "e".....	68
Figure 36 Participant briefing for Phase 2 of experiment 1, here entitled "Section 2" .	69
Figure 37 Briefing and tasks for Experiment 1 Phase 3.....	71
Figure 38 Extract of photographic recording of a route created by an Experiment 2 participant. Note the fourth card is handwritten by the participant and reads " Write and play F major scale".	73
Figure 39 A permutation of the BF algorithm	74
Figure 40 A permutation of the DF algorithm	74
Figure 41 ILOs Marked as Achieved against Experience Coefficient. A data point has been added where two points overlapped at 0.2 on the Experience Coefficient axis.	80
Figure 42 Mean LC Sst score by Approach for each Set. The data points have been offset by a small amount to more clearly show the error bars representing standard error.	88
Figure 43 Main Effect of Set on LC Sst Scores. Error bars show standard error of means.	90
Figure 44 Mean LC Ssq score by Approach for each Set. The data points have been offset by a small amount to more clearly show the error bars representing standard error.	92

Figure 45 Main Effect of Set on LC Ssq score. Error bars show standard error of means.....	94
Figure 46 Main Effect of Approach on LC Ssq score. Error bars show standard error of means.....	95
Figure 47 Mean edit distance score by Approach for each Set. The data points have been offset by a small amount to more clearly show the error bars representing standard error.....	97
Figure 48 Main Effect of Set on Ed score. Error bars show standard error of means..	99
Figure 49 Main Effect of Approach on Ed score. Error bars show standard error of means.....	100
Figure 50 Participant 1 positioning	149
Figure 51 Participant 2 positioning	150
Figure 52 Participant 3 positioning	151
Figure 53 Participant 4 positioning	152
Figure 54 LC Sst of Traversal Approaches by Set	166
Figure 55 LC Ssq of Traversal Approaches by Set	167
Figure 56 Ed of Traversal Approaches by Set.....	167

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List of Tables

Table 1 Fully specified e-learning objective (Gilbert & Gale, 2007, p. 88).....	18
Table 2 Example ILOs with capability and subject matter	19
Table 3 Recreation of “Bloom's Taxonomy in practice”. Published by OpenLearn (2010) (Part 1 of 2)	20
Table 4 Recreation of “Bloom's Taxonomy in practice”. Published by OpenLearn (2010) (Part 2 of 2)	21
Table 5 Use case of the ILO System from the learner's point of view	56
Table 6 Target ILOs	73
Table 7 String transformation showing edit costs.....	75
Table 8 Probability of answering an item correctly due to chance (left) and actual participant correctness (right). “1” represents a correct response, “0” represents an incorrect response.....	78
Table 9 Expected and Observed frequencies of response types from Experiment 1 Phase 1 (Participants 2-4).....	78
Table 10 Coefficients associated with experience level	79
Table 11 Music theory perceived capability and experience coefficients	80
Table 12 Participant route qualities, where CI: correctly included, CE: correctly excluded; WI: wrongly included, WE wrongly excluded, and Exemplar CI: ILOs in route according to the ILO network.	82
Table 13 Total correctly categorised values per route	82
Table 14 Chi Square per route, for combined participant scores.....	83
Table 15 Descriptive Statistics for LC Sst Scores, for each Set (set of ILOs) and each approach, where standard (Std.) error is given by $(\text{standard deviation})/\sqrt{(\text{sample size})}$	87
Table 16 ANOVA summary table of Set and Approach for LC Sst score	88
Table 17 Descriptive Statistics for LC Ssq Score, for each Set and each approach, where standard (Std.) error is given by $(\text{standard deviation})/\sqrt{(\text{sample size})}$	91
Table 18 ANOVA summary table of Set and Approach for LC Ssq score	92
Table 19 Descriptive Statistics for Ed for each Set and each approach, where standard (Std.) error is given by $(\text{standard deviation})/\sqrt{(\text{sample size})}$	96
Table 20 ANOVA summary table of Set and Approach for Ed score.....	97
Table 21 Results of Set 1	163
Table 22 Results of Set 2.....	164

Table 23 Results of Set 3 165

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Academic Thesis: Declaration Of Authorship

I, Teresa Binks, declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

Thesis Title: Routing in Intended Learning Outcome Networks.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission.

Many diagrams in this thesis were remastered by Russell Newman. No changes of intellectual content were made as a result of this.

Signed:

Date:

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To my parents, who were my foundation,
to Russell, who walked *beside* me,
and to Lester, who led the way.

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Acknowledgements

It sound corny, but words here cannot do justice to the love and support I have been blessed by. To everyone that has encouraged me on this journey, thank you. You are treasured.

This thesis could not have been written without the support and guidance of my primary supervisor, Lester Gilbert. In a small class, in my third year, Lester introduced me to new ideas and ways of seeing the world that have irreparably shaped my way of thinking, my motivations, and my life's goals.

Lester has been an amazing supervisor, often giving me what I need, as opposed to what I want. He has been endlessly patient and unfailingly supportive. I'm truly indebted, and I hope in time I can make him proud.

My secondary supervisor, Dr Gary Wills, has been an endless, constant barrage of optimism and cheerfulness, buoying my spirits when things seemed insurmountable. I'm very grateful for his encouragement and confidence in me.

Russell Newman, my partner of eight years, has been instrumental in supporting me through my PhD. This support has included copious amounts of proofreading and the creation of many of the diagrams contained here. More so, he has been a constant companion in life and cheerleader for my efforts. Words cannot express. Thank you.

My parents have inspired and supported me tirelessly for 26 years. I love you so much. My family have surrounded me with love and encouragement and I'm so blessed to have you all in my life.

I'm so grateful to my local support system. To Emma Bates and Chris Burns, for the camaraderie and banter of Tuesday nights. To the members of the Southampton University Shorinji Kempo Club, which manages to consistently attract some of the best people in the world. To Meg and Pete who continue to welcome us into their family. To Maryellen and Rosebay, who provided an vital escape though much of my PhD candidature; once a week I left the academic world and became an awesome person celebrated for my abilities to read stories, blow bubbles, and make a mess. This has been a lifeline.

I'm grateful to the EPSRC for providing the funding that let me take advantage of this opportunity. I'm also grateful to the departments and members of LSL & ESS, and to the University of Southampton, for having me as a student for the past seven years.

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1. Introduction

The last twenty years have seen developments in many facets of technology that can support education. The availability of techniques for producing learning resources is unparalleled; the production of serious games, simulations, interactive tutorials, videos, and computer-aided assessments have become straightforward undertakings. Physical access to equipment, such as mobile, tablet, laptop or desktop computers, is commonplace even in developing countries. Digital content dissemination and curation has taken the form of repositories, Virtual Learning Environments (VLEs), and massive open online courses (MOOCs).

At this point in time, humankind has unparalleled potential to provide pertinent, timely, personalised, and lifelong education.

However, chaos reigns. Globally, resources and courses are disorganised, with no underlying structure by which to navigate, share, or compare them. Educators, teachers, and learners all operate in different systems, with no common language by which to communicate outside of the boundaries of their own course or setting. Effort is duplicated, wasted, or limited to the specific domain and area in which that effort is undertaken.

This thesis posits that employing standardised and shared models when referring to educational outcomes is the next step towards realising the educational potential available through modern technology. Only by using a common language can we come together to converse and collaborate.

The central proposal made in this thesis represents learning outcomes atomically, and links each outcome to other outcomes it enables, and to those that enable it. Rather than being a simplistic and constraining standard, this offers a framework for representing, recording, and discussing conventional educational outcomes. Such standardisation does not offer a panacea to all educational ills, nor is the design or implementation of the specification easy. Nevertheless, this thesis asserts that such standardisation is beneficial, required, and ultimately inevitable.

Educational learning outcomes linked together form an outcome network. Such networks have the potential to be vast and complex, with weighted edges. In order to make complicated networks useful, learners could be offered personalised routes

between nodes, rather than requiring them to interpret the network themselves. This work proposes and evaluates some exemplar routing techniques that can generate content routes that are similar to those generated by contemporary teachers. This forms the basis for systems that could route self-directed learners.

1.1 Introductory Definitions

An ILO is an Intended Learning Outcome, and for the purposes of this thesis, an ILO captures atomic units of academic achievement. It consists of a subject matter item, e.g. "the process of photosynthesis" and a description of what a learner should be able to do with the subject matter, e.g. a capability like "define", "describe" or "explain".

Any ILO can be decomposed into supporting, or enabling, ILOs. In mathematics, in order to perform differentiation, a learner has to be able to multiply. In order to multiply, one has to be able to add. In order to add, one has to be able to count. And so on.

These enablement relationships can be modelled, and yield networks of ILOs.

ILO networks have many potential uses. One of the uses is allowing self-directed learners to effectively route through a domain they are trying to learn.

The term routing refers to the practice of sequencing learning such that a learner can achieve a target outcome, beginning from their existing achievements, by traversing through, and achieving, the intermediate outcomes.

Routing algorithms can be employed to suggest maximally effective routes for various educational purposes.

1.2 Motivations

In addition to using ILOs and ILO networks for route generation, there are other utilities that these models could afford, particularly when combined with other concepts and technologies. This section brings together some of the potential applications that may be realised through the use of ILO-informed systems.

The following sections show how ILOs and ILO networks could be used for indexing, tracking, routing and comparison. This list is non-exhaustive and was generated organically during the course of the research.

Introduction

The following facilities are framed in the context of a theoretical standard of ILO representation, in which each uniquely-identifiable ILO contains fields describing subject matter and capability. ILOs are stored in a repository, and the links between the ILOs are stored in a linkbase. End-user software interfaces with the repository and linkbase to provide views of the ILO networks.

Networks can be shared between, and subscribed to, by other parties. For instance, a qualifications body may publish an accredited network, so it may be utilised by educators and learners. Networks can also be personal, such as those authored by an instructor for a particular course. Networks can also be composites of both. That is, an author can link their network to another network by reference. This link is one way – a network author may link to another author's network without altering the other author's network.

Whilst self-directed learners are the focus of this work, teachers in conventional educational establishments could also take advantage of affordances offered and so facilities for teachers are also noted in this section.

1.2.1 Resource indexing

In an ILO informed system, the unique identifier of an ILO can be used to tag a resource as being relevant to that ILO. This allows teachers and learners to efficiently select resources to support learning.

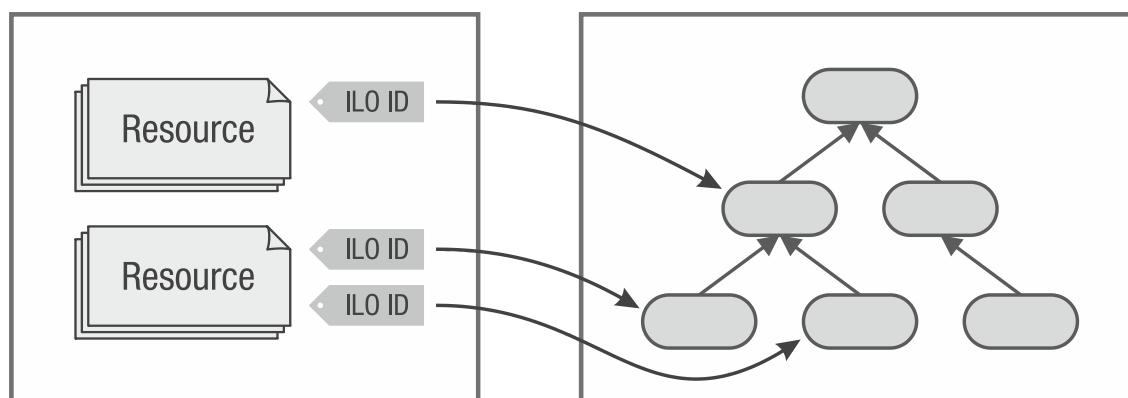


Figure 1 Resource indexing

Resources can address more than one ILO. For example, a video of a volcanic eruption could be used to teach learners about the sequence of an eruption, the effects of an active volcano on an ecosystem, or the cinematic effects employed by the videographer. Any one resource can therefore be associated with multiple ILOs.

Resources need not be merely explanatory. This paradigm holds for inquisitory resources also. Certain computer aided assessment types that model question items discretely (for example, IMS QTI (2006) or QuestionMark (Questionmark, n.d.)) are suitable for resource banking. As such, any learners could easily access informal and diagnostic assessment. With appropriate addressing of security and identity concerns, certificate-bearing summative assessments would also be accessible.

1.2.1.1 Self-Directed Learners

A self-directed learner is a learner who undertakes learning, at any granularity, independently of direction from a teacher. Using ILO IDs to tag resources would allow self-directed learners to choose resources appropriate to the ILOs they are trying to achieve, without the need for teacher intervention. Personalisation techniques could suggest optimal resources for each learner.

1.2.1.2 Teachers

Tagging resources with ILO IDs would allow teachers and other resource authors to share resources within their community and by network comparison, as covered in section 1.2.4.3. Simplified retrieval of varied, trusted resources may result in freeing teachers' time that would have otherwise have been used for searching and curating resources.

1.2.2 *Tracking*

In an ILO informed system, tracking is the action of recording progress though a given set of ILOs.

An ILO network can act as a map of ILOs. The same map can be flattened and then act as a checklist of ILOs. An appropriate flattening process will yield a topological order, which offers the benefits of a properly ordered list of outcomes (where enabling outcomes are listed before those they enable).

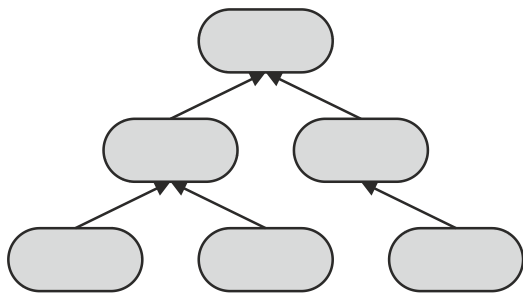


Figure 2 Unmarked ILO network

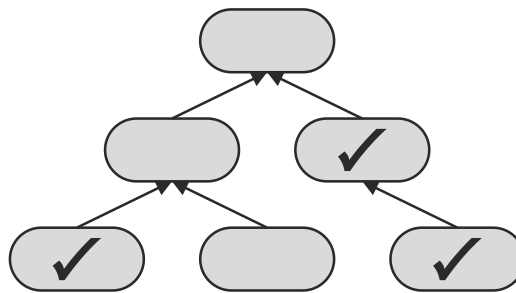


Figure 3 Marked ILO network

Figure 2 shows an ILO network that a student or teacher could use to record which ILOs had been covered or achieved. Figure 3 shows the same network, with exemplar notations.

1.2.2.1 Self-Directed Learners

Self-directed Learners could use the ILO map/list for tracking their own progress, tracking achievement of or confidence in given ILOs. Records of achievements of ILOs could automatically form a portfolio of capabilities.

1.2.2.2 Teachers

Teachers could use the ILO map for tracking an individual student, or lessons delivered to a class. Tracked metrics could include exposure to or achievement of ILOs. Monitoring software or teacher review could alert teachers if a student appears “stuck”, enabling the teacher to offer targeted support and diagnostic assessment in a timely fashion.

1.2.2.3 Other stakeholders

Research projects in education and pedagogy may find tracking ILOs useful. Discrete and unambiguous ILOs could be used as dependant or independent variables for research trials. For example, experiments that alter learning conditions could measure the effects in terms of number of ILOs achieved, the specific ILOs achieved or the time taken to achieve them. This would provide a standard measure to allow comparison between similar research trials, as opposed to test scores or other metrics, which are sufficiently ambiguous as to be incomparable.

1.2.3 Routing

ILO networks can be traversed in order to create routes from one ILO to a super-ordinate ILO via the intermediate ILOs. This would benefit self-directed learners who may lack the ability to route themselves.

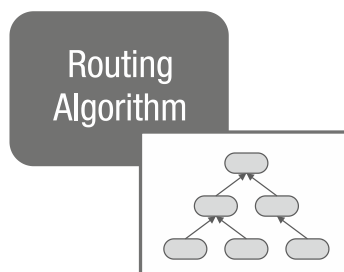


Figure 4 Routing

The ILO networks proposed here are directed acyclic graphs. Any directed acyclic graph will yield at least one topological order. That is, an order of nodes such that for every linked pair ' $a \rightarrow b$ ', ' a ' will always come before ' b '. These orders can be used as routes or paths from a given node to a target node. In this context, this means that a learning route can be derived from any ILO network, and that the route will be pedagogically logical; enabling ILOs will be visited before enabled ILOs.

There are many approaches to routing that can be investigated for pedagogic suitability. Breadth First and Depth First routing algorithms were investigated in this work. Other potential approaches to investigate include:

- Teacher-Set
 - An authority suggests an optimal route through a subnetwork.
- Normative Fail-Safe
 - A route is adapted with respect to the performance of the students using it. If more students are successful with a particular route, then this route should be promoted. Similarly, if many students struggle on a particular route, then this should be an indication that the route and the relevant part of the network should be inspected for faults.
- Student-Chosen
 - Students choose the next ILO they want to achieve.

Introduction

- Patterns
 - It is possible that further development will reveal certain patterns within the network; topographical patterns of capability, subject matter, or both. This is similar to the intermediate representation tiling concept in compiler engineering. The DT pattern (See section 3.2.3.2) is an example of such a pattern in an ILO network. There may be optimal ways of routing through such repeating patterns.
- Subject Matter or Behaviour Type
 - Certain subject matter topics or items may be “easier”, or more efficacious for certain students, particularly when considering student background and prior experience. Strategic routing to those ILOs may be employed to optimise student engagement.
- Flow (in education)
 - “Flow”, in this context, refers to a state of deep engagement with an activity, characterised by the learner being “in the zone”, and often oblivious to their surroundings or the passage of time. Learning activities that bring about flow present a level of challenge that is appropriate for a learner, neither so hard as to be frustrating, nor so easy as to be boring. Flow was proposed by Csikszentmihalyi (1990). It may be possible to facilitate flow with appropriate routing.
- Diagnostic Assessment
 - A learner’s failure to achieve an ILO may be due to insufficient preparation in terms of prerequisite ILO achievement. Sufficiently comprehensive elaboration of the prerequisite ILOs and purpose-built algorithms could allow a system to present assessments that would locate the area(s) of weakness.

This list of routing strategies is not exhaustive, and was devised during the course of research for this thesis. Further development would likely result in other routing strategies being devised.

1.2.4 Network Comparison

The specific and sufficiently unambiguous nature of ILOs and ILO networks allows two or more networks to be compared. This comparison could yield several benefits.

Any two ILO networks covering the same topic can be compared, both programmatically (searching for patterns of nodes, or resources in common, for example), and by humans. ILOs that are deemed similar enough to be considered equivalent could be notated as such.

This would be useful for enhancing structures via the mechanisms of consensus mapping, resource sharing, quality control, and profile matching as explored in the following sections.

1.2.4.1 Enhancing Networks

Network comparison could lead to enhanced or refined networks.

Consider the case: Two teachers create a network each of, ostensibly, the same subject matter. They are depicted in Figure 5 and Figure 6.

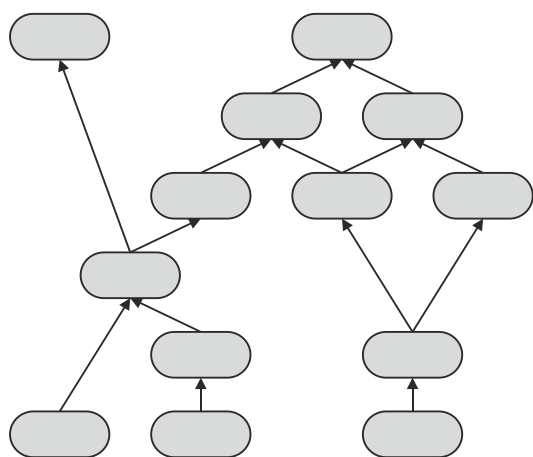


Figure 5 Exemplar network 1

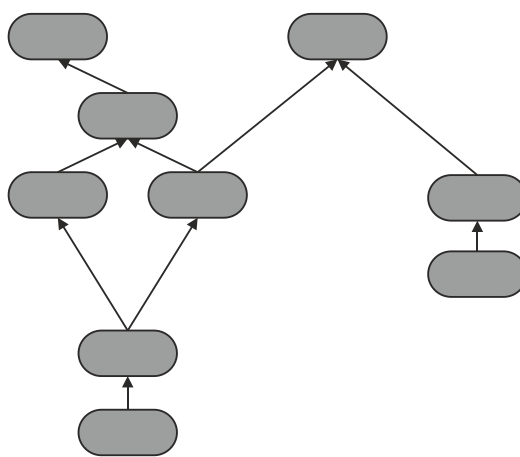


Figure 6 Exemplar network 2

The overlap between the two structures can be found, as shown in Figure 7. This figure shows an area of overlap. Overlapping ILOs are those that have been declared equivalent by at least one stakeholder.

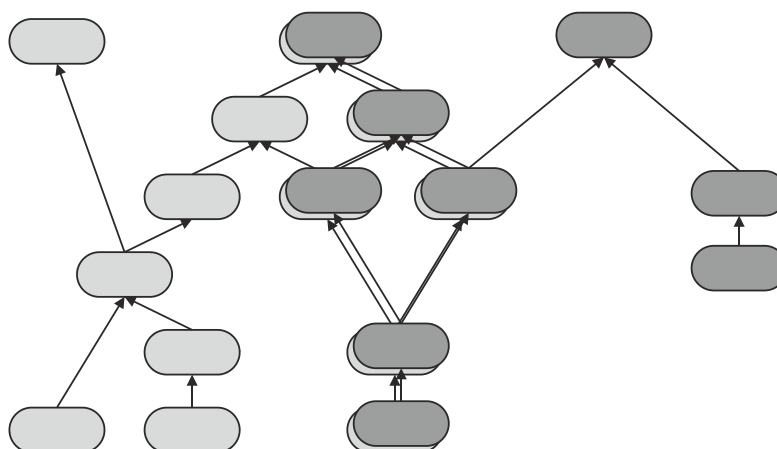


Figure 7 Overlapping networks (widening)

Both networks feature equivalent ILOs, so students traversing either structure may identify the interrelation and choose to traverse more widely, “crossing” networks. In this work, this is labelled “widening”. Similarly, it is possible to compare networks for the purposes of linking simpler ILOs to more “difficult” ones, as shown in Figure 8, here labelled “deepening”. This could be considered analogous to schooling levels or grades of work.

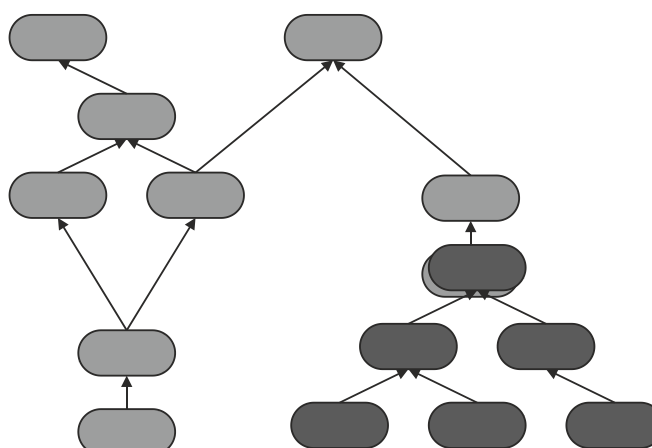


Figure 8 Overlapping networks (deepening)

In this way, multiple networks may be composed to create large, and effectively comprehensive, networks of ILOs, as illustrated in Figure 9.

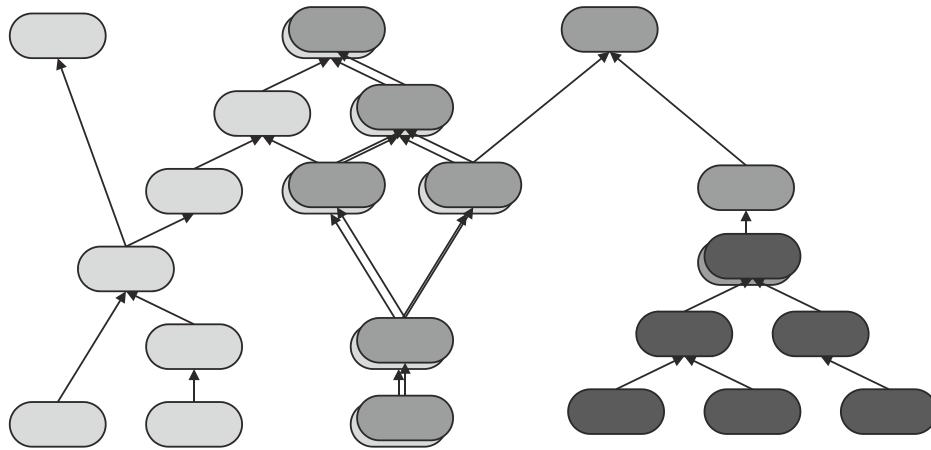


Figure 9 Multiple overlapped networks

Defining courses and curricula within an ILO system moves away from typical curricula representation forms of flat or indented lists. On an ILO network, courses and qualifications become outlines drawn around sub-networks. Tiered courses become nesting shapes, with the more basic outcomes innermost, surrounded by rings of more advanced outcomes. Educational courses could become more coherent and continuous with less of the repetition typically experienced when attending multiple courses.

1.2.4.2 Consensus Map (most necessary and sufficient nodes)

ILO network comparison has the potential to yield “consensus maps”. Comparing multiple networks could yield sub-networks that teachers have in common, represented by areas of overlap such as the central portion of Figure 9. The degree of overlap may be an interesting metric to explore. If several authoritative networks were composed, the areas of frequent overlap would indicate ILOs considered by many to be important for achieving certain top level outcomes. Those that are densely overlapped may represent the minimum ILOs for necessary and sufficient routing, whilst the sparsely overlapped ILOs are less likely to be essential.

1.2.4.3 Resource Sharing

ILO networks comparison could be used to facilitate resource sharing. If the same ILO appears on two different networks, and each network has a different resource associated with it, then it is possible that those resources can be used interchangeably. This would increase the number and variation of resources available to students, potentially allowing them to find resources that are most helpful to them.

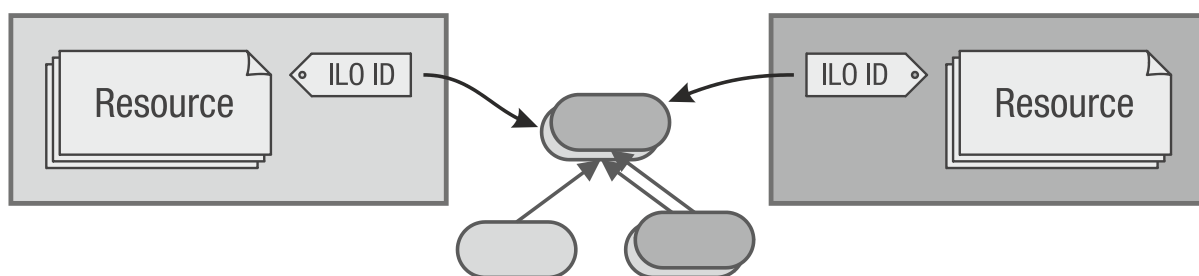


Figure 10 Overlapped networks showing resources

In Figure 10, the light grey resource, attached to the shared ILO, could be used by a student who had previously been using resources linked to by the dark grey network, and vice versa.

The specific and well-defined nature of ILO networks would afford the reuse of more sophisticated resources. Teaching games (“serious games” (Hess & Gunter, 2013)) could generate their content from an ILO network. Depending on the game and the network, the same game mechanism could be used with another similar ILO network. For example, a puzzle game that teaches French by having the learner solve a mystery by reading French and navigating a French town could possibly be adapted to German. Advances in language processing and translation could lead to a situation when such a game runs with whatever dictionary is provided to it.

1.2.4.4 Quality Control

ILO network comparison could be used as a metric of quality for a course, and indirectly an institution, should the quality of the courses be used to judge the quality of their institution. Comparing an authoritative network to that of an individual or institution may indicate the quality of the network. The British Computer Society could formulate a network of ILOs, and compare that with universities’ networks. Hypothetically, those meeting an arbitrary threshold of coverage between the linked networks would likely be eligible for accreditation by the BCS.

1.2.4.5 Profile Matching

In an ILO-informed education paradigm, a learner would have a record of ILOs achieved. This would form a portfolio, as mentioned in section 1.2.2.1. Such a network of achieved outcomes could be compared to a network prepared by an employer seeking to fill a job role. This would give a detailed indication of which candidates meet the capabilities needed for the position, and where further training would have to

be given, a problem not addressed by HRXML. This comparison between a theoretical ideal and the capabilities of real staff has applications in continuous professional development contexts, and official certification requirements. The same mechanic could also be used for admitting or transferring students to or between educational courses. This portfolio would be used for tracking lifelong learning.

Profiling like this may also be able to predict interactions with ILOs not yet attempted. Tracking the order in which students choose to approach ILOs, or what resources they use, or how long they take to achieve an outcome, is another way of profiling students. Patterns may emerge – apparent difficulty with an earlier ILO may predict issues with a future ILO. A change in interaction behaviours with the system could be an indicator of changes to the learner themselves.

1.2.5 Motivation Overview

The utilities offered described in the previous sections, and other utilities and benefits not yet conceived, could form a system that supports pertinent, timely, personalised, and lifelong education, potentially for the world. Figure 11 shows an overview of some of the utilities afforded by ILO informed systems.

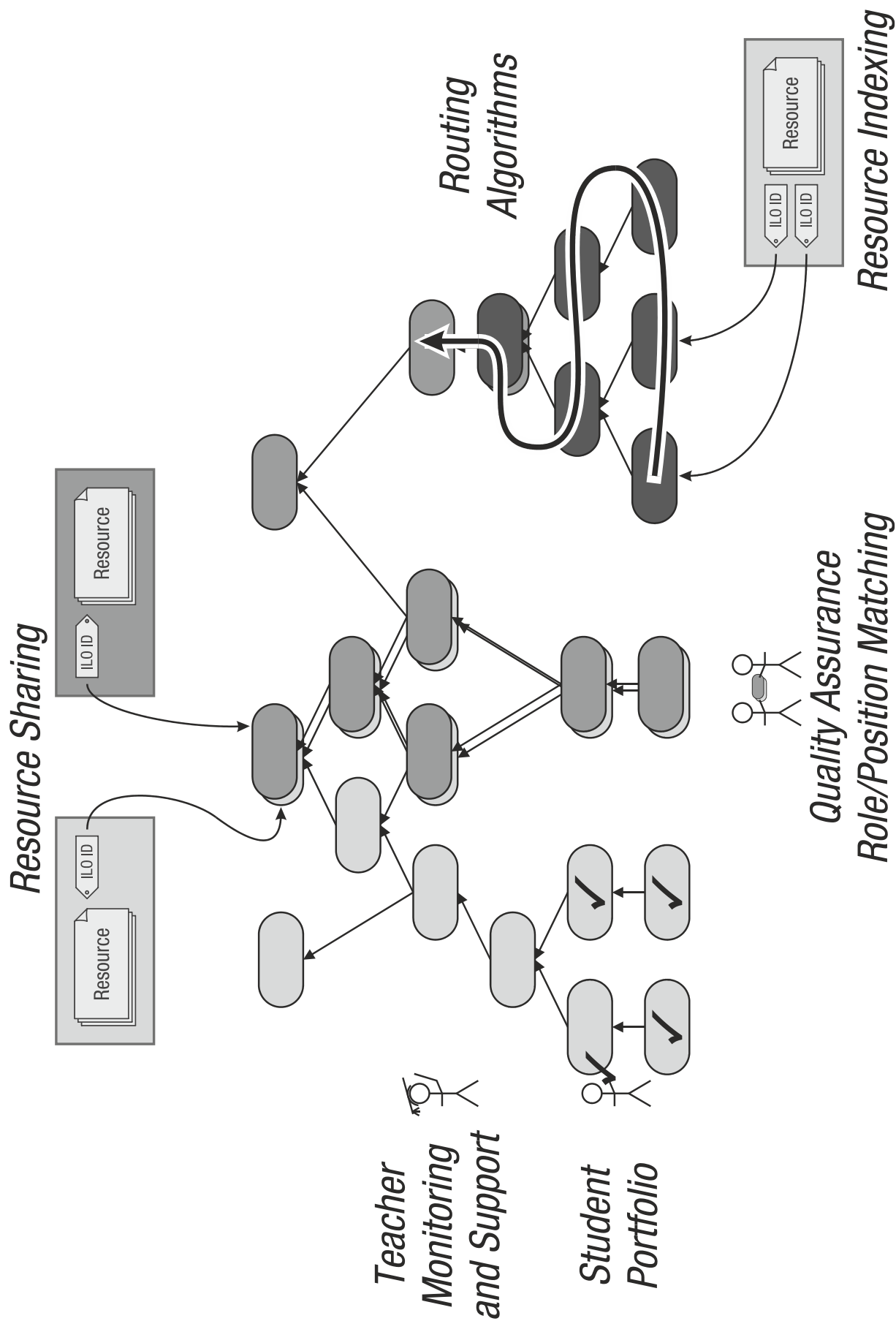


Figure 11 An overview of some of the potential utilities afforded by ILO informed systems.

1.3 Research Aims

Section 1.2 presents many avenues for investigation, far more than are within scope of a single doctoral work. This thesis focusses on routing. It aims to explore how the routes generated by algorithms navigating an ILO network compare with routes generated by teachers. Future work would create algorithms that can produce routes with the same effectiveness as teachers. This focus can be expressed as a research question:

To what degree do routes of ILOs generated by algorithms differ from sequences of ILOs generated by teachers?

Ultimately, such algorithmic navigation techniques could support self-directed learners in many settings and scenarios, providing and building upon benefits offered by other similar services such as Intelligent Tutoring Systems (section 2.5.2) and Adaptive Educational Hypermedia (section 2.4.3). In order to fulfil this potential, self-directed learners would have to be able to interpret ILOs. This research therefore also aims to investigate the abilities of such learners in interpreting ILOs and ILO networks. To pursue these aims, an ILO network was composed and validated, and routing algorithms were devised. These were used to answer the questions:

Do non-subject matter experts understand and correctly interpret the specification and model for ILOs?

Do non-subject matter experts understand and correctly interpret the specification and model for ILO Networks?

Can non-subject matter experts relate the model to their own capabilities, that is, can they self-report their proficiency in a subject area in terms of ILOs?

Specifications and models of ILOs and ILO Networks in contemporary literature are explored in section 2.2.

1.4 Scope

This thesis explores the research area surrounding ILOs, ILO networks, and routing algorithms. It is limited to the cognitive domain (outcomes pertaining to academic

capabilities, as opposed to physical or emotional capabilities) and addresses learners in mainstream education, and without redress to special educational needs.

1.5 Structure

This thesis consists of eight chapters. Chapter 1 introduces the project, the background, the research questions and the scope. Chapter 2 covers the state of the art that this work builds upon. Chapter 3 discusses the research, and proposes a synthesised system to address the gap in the research. Chapter 4 states the research questions and hypotheses that were studied, and the approaches that were taken to test them. Chapter 5 details the results of the experiments, which are then discussed in Chapter 6. Chapter 7 offers conclusions to the work, with Future Work detailed in Chapter 8. A list of references and the appendices follow.

1.6 Summary

This chapter posits and evidences that there is a mismatch between the educational potential offered by contemporary technology and the degree to which we are exploiting that potential. It suggests that a necessary step towards realising that potential is to standardise the way we structure student outcomes. This thesis suggests ILOs and ILO networks as a candidate for this standard, where an ILO consists of a demonstrable capability verb and an item of subject matter.

The affordances of such structures and systems motivate this project. ILOs and ILO networks could offer benefits to numerous stakeholders. Indexing resources to the ILOs they address could simplify, facilitate, and increase the sharing of resources, drive up quality, reduce redundancy, and save effort. Tracking individuals and classes of learners could allow learners, teachers and auditing stakeholders to monitor progress more easily, and give ownership of learning progress to the learners. Routing offers benefits to self-directed learners in many contexts, particularly where teaching infrastructure is not available for their subject or logistical requirements. ILO network comparison has affordances in network expansion via linking, and in curriculum quality assessments.

The motivations for this project present many avenues for investigation. This thesis focusses on routing, seeking to test whether algorithmic routing strategies would be sufficient to route self-directed learners, at least as well as contemporary teachers do.

Introduction

This research therefore also aims to investigate the abilities of such learners in interpreting ILOs and ILO networks.

Chapter 2 begins to explore the issues identified in this chapter, with a report on the current state of the art in learning and teaching, ILOs and similar specifications, and the benefits and drawbacks inherent in such approaches.

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2. State of the Art

This chapter introduces the background to this work, and the foundations upon which the contributions here are made. Learning and teaching are defined. The roles of the teacher and the learner are framed within the learning transaction and the purpose of the learning transaction is modelled as an intended learning outcome. Learners who teach themselves are defined as self-directed learners, and their challenges are examined. The challenge of routing through ILOs is explored in more detail, with analogies drawn between minimal guidance pedagogies and adaptive hypertext.

The final sections explore contemporary work that is similar to proposals in this thesis and reports on technologies and practices that could be integrated the proposals in future work.

2.1 Learning and Teaching

Learning and teaching are interrelated practices. This section introduces both, and shows a model of interrelation called the learning transaction.

2.1.1 Learning and eLearning

The nature and definition of learning remains contested, with views from psychologists, neurologists, educators and philosophers all subtly different. A thorough examination of the philosophical and abstract opinions of what learning is falls out of scope of this project. Instead, this section presents a functional sample of material that this work is built upon.

This thesis employs a behavioural view of learning, commonly associated with psychologists of the mid 1900's, such as B.F Skinner. In a survey chapter, Burton, Moore, & Magliaro (1996) state that a common view is that learning can be defined as a change of behaviour due to an experience. This view forms the basis for the definition used within this work.

eLearning is related to learning, and is a term with many definitions ranging from

We will call e-Learning all forms of electronic supported learning and teaching, which are procedural in character and aim to effect the construction of knowledge with reference to individual experience, practice and knowledge of the learner.

Information and communication systems, whether networked or not, serve as specific media (specific in the sense elaborated previously) to implement the learning process.

(Tavangarian, Leybold, Nölting, Röser, & Voigt, 2004)

to

(...) we define e-learning as training delivered on a digital device such as a smart phone or a laptop computer that is designed to support individual learning or organizational performance goals.

(Clark & Mayer, 2011)

and

a broad combination of processes, content, and infrastructure to use computers and networks to scale and/or improve one or more significant parts of a learning value chain, including management and delivery.

(Aldrich, 2004)

While definitions vary widely, they all share the characteristic that they use computerised tools for supporting learners.

2.1.2 Teaching

A Google image search for “teaching” returns multiple images of an adult, standing at a chalk or wipe board, addressing a class of children. These images imply teaching is a simple task of presenting information, and possibly classroom management. Far from this simplistic characterisation, teaching can be considered equally as complex and subtle as learning, and teaching occurs far more often and in far more contexts than the stereotypical classroom setting.

Teaching is multifaceted. In addition to the content presentation role, teaching involves many other skills. Harden and Crosby (2000) outline twelve roles of teachers within the medical profession, including role modelling, mentoring, assessing, and planning.

Teachers can influence how students feel about a subject area. Patrick, Hisely and Kemplar (2010) discuss the impact that teacher enthusiasm has on student enthusiasm, reporting that students given an engaging and passionate presentation had higher levels of intrinsic motivation in their learning activities. Bax (1997) lists

State of the Art

teaching roles and tasks such as knowing the background of learners, evaluating programmes, and fostering a positive atmosphere as part of being an effective trainer.

Part of the responsibility for the provision of an environment conducive to learning falls under to teachers (Cohen, 2006). The Association of School and College Leaders (2004) and the United Kingdom Department for Education (2012) list pastoral support amongst teacher and support staff duties.

Kirschner, Sweller & Clark (2006) define “direct instructional guidance” (here analogous to teaching) as providing both complete topic knowledge and strategy support for learners that is congruent with the state of the art in the understanding of human cognition. That is, the teachers present not only the content, but help students learn the content by supporting appropriate learning activities. Conversely, Hmelo-Silver (2004) states that “The teacher acts to facilitate the learning process rather than to provide knowledge”.

Teachers are also tasked with assessing students’ learning. This task is encapsulated in the learning transaction in section 2.1.3.

A special case of teaching is tutoring: the teaching of a single pupil (or a very small group) (Oxford University Press, n.d.). Tutoring is of particular interest as it has been shown to produce considerably greater gains in achievement for students, compared to the conventional classroom approaches.

Benjamin Bloom summarised a study by two of his doctoral students, Anania (1982/1983) and Burke (1984). Their study showed that one-to-one tutoring produced achievement gains two standard deviations (“2 sigma”) over conventional classroom instruction in groups. Bloom recognised the logistical difficulty in providing one-to-one tutoring and used his publication to call on the research community to solve the two-sigma problem by devising alternate approaches that would produce similar gains (Bloom, 1984).

Tutoring, as a special case of teaching, seems to be the gold standard of instruction, producing the most significant impact on student achievement.

With the proliferation of computing resources since Skinner’s time, software solutions for tutoring have been devised and built. Corbett (2001) reports on several meta-analyses of “first generation” tutoring technologies which show effect sizes from 0.3 SD (standard deviations) to 0.48 SD. Some years later, Nicholas & Martin (2008) report that “the best” intelligent tutoring systems can perform 1 SD over classroom teaching

in terms of learning gains (p. 2). Specific examples of software that may be classified as tutoring technologies are shown in sections covering adaptive hypertext in 2.4.3, teaching machines in 2.5.1, and Khan Academy in 2.5.3.3.

In this section, the roles of a teacher have been explored. Teachers perform many types of task during instruction such direct instruction and facilitation, and supporting students pastorally and psychologically. Software solutions have been devised in an attempt to deliver the best teaching for a reasonable logistical cost. The next section shows how learning and teaching interrelate within the learning transaction.

2.1.3 The Learning Transaction

Learning and teaching interactions, covered in the previous sections, can be seen in the macro level in the context of courses, modules and lessons. Interactions can also be modelled at the atomic level, as a transaction between some learner entity and some teaching entity. Laurillard (2002) describes this as the “conversational framework”, and Gilbert & Gale (2007) simplify it as shown in Figure 12, called the “learning transaction”.

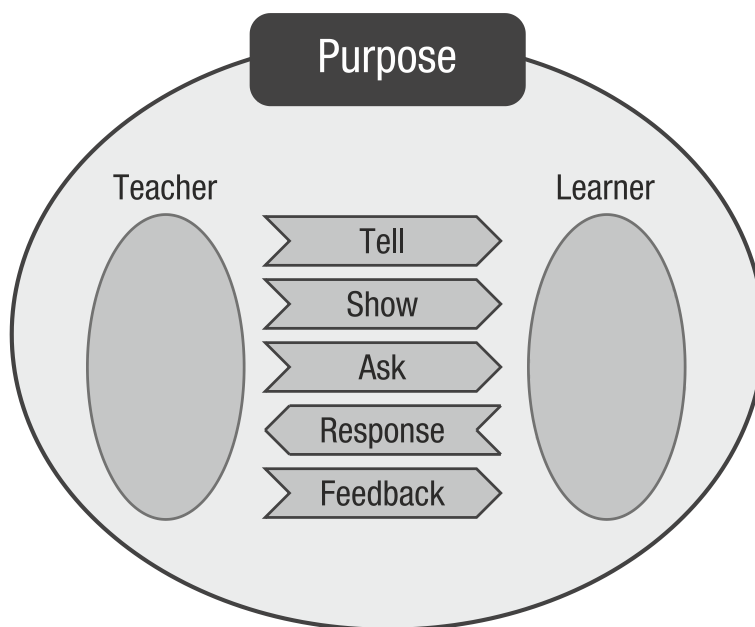


Figure 12 Learning Transaction adapted from (Gilbert & Gale, 2007)

This diagram shows two actors (or agents) – a learner and a teacher. The teacher presents information to the learner in the “show” and “tell” phases. The teacher asks

the student to perform some task. The learner performs the task, and the teacher provides feedback. This can be on the smallest instructional level, for example, a child being instructed in colours: “This colour is green.” “What colour is this object?” “Yes, this is green”, or, “You chose yellow”.

Depending on the depth analysed, this cycle could happen hundreds of times in a typical 45 minute classroom lesson.

There are two important points to note in discussing the learning transaction. Firstly, the teacher and student actors represent roles, and not necessarily people. This means that a person can be both the teacher and the student, and is plainly seen when considering someone learning something from a book – no directed teaching may occur, but if a student is able to say, do or demonstrate something new as a direct result from engaging with the book, then learning has occurred. Montessori (1967) and Reggio Emilia pedagogies call for the environment to be a teacher (Gandini, 1998).

The second point of note concerns the circle around the learning transaction, headed “purpose”. Gilbert & Gale include this notation to show that the learning transaction is targeted – there must be an intentioned outcome for the learning transaction. If there were no intention, the teacher role would not be required. The learning transaction therefore addresses an ILO, as shown in Figure 13.

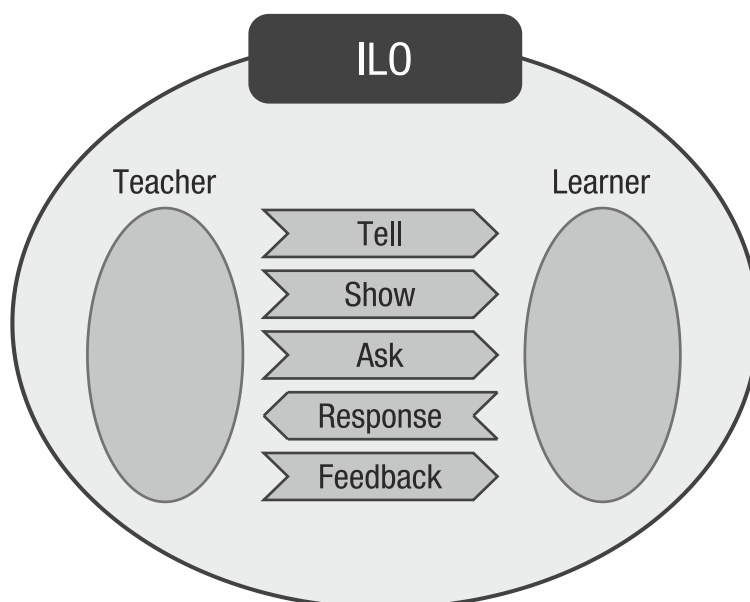


Figure 13 Learning Transaction adapted from (Gilbert & Gale, 2007), showing how each learning transaction addresses and ILO

Self-directed learners (see section 2.3) are loosely defined as learners who teach themselves. Gilbert & Gale's model shows us that self-directed learners are those who teach themselves, that is, they play the teacher role for themselves.

The learning transaction shows the interplay of learning, covered in 2.1.1, and teaching, covered in 2.1.2. A learning transaction is undertaken for a purpose, which is modelled as an ILO, and is covered in the next section.

2.2 Intended Learning Outcomes (ILOs)

This section examines the definitions of ILOs used in the relevant literature and introduces the working definition used in this thesis. Taxonomies of capabilities and subject matter are investigated. The decomposition of ILOs into enabling outcomes is covered. Issues and concerns regarding the use of ILOs are explored, followed by a sample of the benefits they afford.

2.2.1 Defining ILOs

ILOs have become a prevalent concept in education, and varying definitions of ILOs are commonplace in contemporary literature. The landmark study in this domain came in 1954 with the publication of “Taxonomy of Educational Objectives: The Classification of Educational Goals” by the committee chaired by Benjamin Bloom (see section 2.2.3). Bloom’s work presented “Educational Objectives” which are structurally and conceptually similar to the ILOs presented here. Another viewpoint would credit the introduction of teaching machines as the first use of atomic instructional items, with the first teaching machine developed in the 1920’s (see section 2.5.1). References to ILOs remain in the literature and have gained attention in recent years due to political and academic interests (Overton, 2005).

Most of these definitions in the literature state that an ILO describes what a student will be able to do at the end of a period of instruction. Most definitions require these outcomes to be more specific than ‘to understand’ or ‘to appreciate’, where the evidence of achieving the outcomes should be observable. The following samples illustrate the variety, similarities, and differences between these definitions.

2.2.1.1 Textual Definitions

The definitions presented in this section are typically issued as guidance for educators writing course specifications. This section will not cover machine processable definitions; these are discussed in the next section.

The University of Glasgow’s Learning and Teaching Centre states that ILOs carry a specific meaning, describing what a student should be able to demonstrate regarding particular knowledge, skills, and attitudes once instruction is complete. They recommend writing ILOs using an active verb in conjunction with an object and an indication of context (University of Glasgow, n.d.).

The University of Southampton's Quality Handbook defines learning outcomes as a specification of knowledge, skills, or other attributes that someone will be required to demonstrate in order to pass a unit (University of Southampton, n.d.).

The University of Cambridge's Educational and Student Policy office states that learning outcomes inform students about the "kinds of knowledge that they will be given the opportunity to acquire". The advice stresses that ILOs are concerned with the achievements of the learner, as opposed to the intentions of the teacher. The specifications do not include capability verbs, in contrast to most other definitions. Examples given include "[students will have] acquired a basic knowledge of physics and chemistry sufficient to understand the physical and chemical bases of biological subjects taught in the course;" and "[students will have] acquired the ability to use mathematical and statistical techniques relevant to the biological subjects taught;" (emphasis in original removed). (University of Cambridge, n.d.)

The Higher Education Academy, an organisation supporting the higher education community in the UK, suggests using learning outcomes to define courses by what a student will be able to do at the end, rather than defining a course by what they will have been taught (Overton, 2005). They stress that students must be able to demonstrate their achievement of the outcomes and qualify that verbs such as "understand" and "appreciate" do not describe behaviours with the required degree of specificity.

Johnson (2003) defines ILOs as:

[...] simple statements of desired learning and performance outcomes that consider behaviors to be demonstrated as a result of a learning intervention, the conditions under which the learning is to be demonstrated, and the degree of mastery that will be expected from that performance.

(p. 2)

Harden (2002) states:

Learning outcomes are broad statements of what is achieved and assessed at the end of a course of study. (p. 2)

Barrit, Lewis & Wieseler (1999) state:

Objectives tell the Learner what they must do in order to achieve mastery.

(p. 8)

State of the Art

These definitions are typically framed for use of the learner, and by extension, stakeholders who are interested in learner achievement. There are varying degrees of specificity, covering brief descriptions of behaviour, through to more thorough qualifications of suitable structure and verbs.

The definitions presented in this section are intended to be understood by humans. They are characterised by falling at the abstruse end of a spectrum of ambiguity. As they are designed for communication between learners, teachers and related stakeholders, the definitions have been crafted with an implicit expectation that human reasoning will clarify the meanings when they are interpreted. These definitions represent contemporary understanding of ILOs. However, the system described in the Motivations (section 1.2) relies upon well-specified, unambiguous ILOs. These definitions, in their current forms, are not fit for the purposes described in that system.

The overarching concepts of descriptions of behaviour, interpretability for a range of stakeholders, and demonstrable verbs are carried forward into this work's definition in section 2.2.2.

The next section shows definitions that claim to have some degree of machine processability.

2.2.1.2 Machine Processable Definitions

The previous section explored textual and unstructured definitions of ILOs. Contrasting this, the following examples show machine processable ILO specifications. The ILO portion of these specifications is frequently and perhaps somewhat surprisingly represented as an unstructured or loosely-structured aspect of a model, such as a free-text area, limiting the potential of machine processing.

2.2.1.2.1 HR-XML

Human Resource eXtensible Markup Language (HR-XML) is a specification for HR interoperability, created by HR Open Standards (previously the HR-XML Consortium ("HR-XML Is Now HR Open Standards, Continuing Its Commitment to Simplify Human Resource Technology Integration," n.d.)). HR Open Standards is an organisation dedicated to developing specifications for human resource data exchanges. It is included here as an example of a system that uses the terms of competency in a formal manner, but does not do so in a way that enables machine processing of the competences.

HR-XML can be used to specify human resource roles and the skill or competencies a role requires. The specification includes a type called PositionCompetency, intended for representing desired abilities and skills. HRXML does not specify the content or structure of a competence within the PositionCompetency field, or any way of structuring multiple competencies.

[Definition of] PositionCompetency: A qualified position competency has a specified required and/or desired level of proficiency and has an explicit or implicit level of importance (weight) among sibling competencies associated with a position. (Position Competency Model: Supporting Library Components, n.d.)

The representation of the XML instance is shown in Figure 14.

```
<PositionCompetency>
  <CompetencyID>...</CompetencyID> [0..*]
  <CompetencyName>...</CompetencyName> [0..1]
  <TaxonomyID>...</TaxonomyID> [0..*]
  <Weight>...</Weight> [0..1]
  <RequiredProficiencyLevel>...</RequiredProficiencyLevel> [0..1]
  <DesiredProficiencyLevel>...</DesiredProficiencyLevel> [0..1]
  <ProficiencyAcquisitionDifficulty>...</ProficiencyAcquisitionDifficulty>
  > [0..1]
  <CompetencyClassificationCode>...</CompetencyClassificationCode> [0..*]
  <CompetencyDimension>...</CompetencyDimension> [0..*]
  <RelatedCompetency>...</RelatedCompetency> [0..*]
  <CompetencyEvidenceRequirements>...</CompetencyEvidenceRequirements>
  [0..1]
  <AttachmentReference>...</AttachmentReference> [0..*]
  <UserArea>...</UserArea> [0..1]
</PositionCompetency>
```

Figure 14 HR-XML PositionCompetency (“Position Competency Model: Supporting Library Components,” n.d.)

The PositionCompetency node is used in an XML item named PositionOpening. This node contains the data that a recruitment officer would need to advertise the requirements for a job. Figure 15 shows an example concerning abilities in data modelling:

```
<CompetencyName>Data Modeling</CompetencyName>
<RequiredProficiencyLevel>
  <ScoreNumeric minimumScoreNumeric="1" maximumScoreNumeric="10">8</ScoreNumeric>
</RequiredProficiencyLevel>
```

Figure 15 HR-XML Competency (“Position Opening: Examples,” n.d.)

State of the Art

HRXML's flexibility comes from its lack of formal semantics. However, this flexibility also results in difficulties when trying to develop interoperable systems (Knight, Gasevic, & Richards, 2005).

2.2.1.2.2 Europass Language Passport

The Europass Language Passport is part of a portfolio project funded by the European Union. The passport is designed to "record skills and competences in Languages" (Council of Europe and European Union, 2010). The portfolio is intended to assist learners in making their language qualifications portable within Europe (Finch, 2009). The portfolio consists of documents, for which there are templates, but little guidance on how to fill them in. Karampiperis, Sampson & Frytos (2006) criticise the project for its lack of machine processability which he claims limits the interoperability of a system meant to increase the mobility of citizens and the portability of their experience and qualifications.

2.2.1.2.3 IMS Reusable Definition of Competency or Educational Objective (RDCEO)

IMS Global is a not-for-profit organisation that supports the use of computing technology in state and corporate education around the world. IMS publishes educational technology standards, authored with input from their member organisations.

IMS' RDCEO is a brief specification that "(...) defines an information model for describing, referencing and exchanging definitions of competencies (...)" (IMS Global, 2002). ILOs form the core of competencies in RDCEO, so many discussions regarding competencies are relevant to ILOs. Competencies are covered further in Appendix D.

RDCEO consists of four mandatory fields: Identifier, Catalogue, Entry and Title. Identifier is a globally unique label. Catalogue indicates the organisation that created the competence and Entry is the ID of the competence within the cataloguing scheme. Title gives a textual (presumably human-readable) description of the competence. RDCEO uses optional fields to provide human-readable information about the competency, such as referring to what model it follows and allowing the author to specify types, such as "Conditions" or "Standards".

RDCEO is intentionally vague about the use of competences, or how they are formalised, other than providing an unstructured textual definition for exchange by machine, and interpretation by humans. It also deliberately ignores the concept of competencies that make up other competencies.

2.2.1.2.4 So-called Machine Processable Definitions

These machine processable specifications of ILOs or analogous concepts are, in fact, generally no more detailed nor truly machine processable than their textual counterparts covered in section 2.2.1.1. All three of these mainstream specifications secrete the core ILO definition into variations on a free text area. This makes these “machine processable” definitions virtually identical to the textual definitions, save for the ability to tag fields and properties onto a given instance of an ILO. Should those fields or tags be substantive in their descriptions of behaviour or subject matter, then the claim of the machine processability of these specifications would be corroborated. However, such properties of the specifications investigated here do not constitute machine processable definitions.

2.2.1.3 Knowledge Space Theory

Knowledge Space Theory (KST) is an approach to formally modelling learning outcomes, where problems (assessment items) are used to represent learning outcomes. KST uses a mathematical model, where content items are arranged in sets, and the knowledge of the learner is modelled as a set (Heller, Steiner, Hockemeyer, & Albert, 2006). This approach bypasses the difficulties of unambiguously defining ILOs with words, by simply stating that a learner can solve a given problem. Deriving the competence from the statement is left to the interpreter.

KST offers an alternative to ILOs. It is a solid approach to modelling problem spaces, and users capabilities within problem spaces. However, KST in its current incarnation has several drawbacks. The verbose-ness of some problems makes it difficult to gain useful overviews of a subject area or a learner’s position. The mathematical roots of KST show through in documentation of the standard, and can render some parts of the specifications inaccessible to those with insufficient mathematical background. It is unclear how scalable KST based systems are in practicality. An ILO, as described in section 1.2, carries an implicit expectation of human interpretation, and thus accept a given level of ambiguity. This allows a single ILO to summarise several others, such as how the ILO “solve quadratic simultaneous equations I” implicitly contains “solve $y = x^2 - 9x + 20$ ” and all variations thereof. The literature on KST does not show how the specification would generalise or model those variations.

This section has shown the myriad definitions of ILOs in the contemporary literature. There is little formal agreement on how an ILO should be modelled, other than most

definitions calling for some representation of capability, and some representation of subject matter. The next section shows how ILOs are defined in this work.

2.2.2 The Definition of ILOs in this Work

This section specifies the form of intended learning outcomes used in this work, and investigates useful supporting taxonomies.

Gilbert and Gale defined an “e-learning objective” (2007, p. 88) as shown in Table 1.

Situation	Given a situation A
Constraints	And given constraints B
Basic Objective	The student will be able to X
Standards	According to performance standards C
Tools	Using tools D

Table 1 Fully specified e-learning objective (Gilbert & Gale, 2007, p. 88)

In this work, an ILO is defined as a **capability** associated with some **subject matter**. This definition is based upon Gilbert & Gale’s definition.

In section 2.2.1, criticisms were levelled at contemporary textual and so-called machine processable specifications of ILOs. These criticisms mainly focussed on the free text nature of the ILOs, and the inherent lack of specificity that free text allows. The definition given above is similar to those specifications in that it does not, in this form, appear any more rigorous. However, it does mandate the inclusion of a demonstrable behaviour with some given subject matter. The rigour and exactness necessary to support the system described in the Motivations section 1.2 , is explored in section 3.1.3. This exploration includes the use of use of taxonomies, covered in the next section, to increase ILO precision.

As specified by the definition of learning from 2.1.1, ILOs describe the observable evidence of learning. Table 1 shows some exemplar statements of student capability, and identifies the ILOs within those statements.

Typical Example	Capability Verb	Subject Matter	ILO
Lucy can define “radio waves”	define	radio waves	define radio waves
Ben can solve simultaneous equations	solve	simultaneous equations	solve simultaneous equations
Alex can analyse logged data	analyse	logged data	analyse logged data

Table 2 Example ILOs with capability and subject matter

Technically, “define”, “solve” and “analyse” are not observable. Writing or otherwise expressing a definition, a solution or the results of an analysis is. Issues around such specificity are explored in section 2.2.5.

This section has introduced the definition of learning outcomes. A learning outcome comprises an observable behaviour and subject matter. The verbs used for describing observable behaviours and subject matter can be drawn from established taxonomies. The following subsections cover taxonomies that can be used to support the specification of intended learning outcomes.

2.2.3 ILO Capability Verbs

Bloom’s cognitive taxonomy (Bloom, 1956) specifies categories of behaviours that can be used in intended learning outcomes. The taxonomy specifies six categories: Knowledge, Comprehension, Application, Analysis, Synthesis and Evaluation. Each category expresses a behaviour that the authors considered appropriate to exemplify the meaning of the category. Bloom and his committee wrote taxonomies relating to the cognitive domain, the affective domain and the psychomotor domain. The denotational scope of this project is restricted to the cognitive domain, but its connotational scope includes affective and psychomotor, as well as other putative domains such as social, moral and affective.

There are many sources on- and offline that have built upon Bloom’s cognitive taxonomy and expanded the list of capability verbs under each category. Several of the sources listed in section 2.2.1 suggest Bloom’s taxonomy as a source for verbs to describe behaviour.

Table 4 and Table 5 show one derivation of Bloom’s taxonomy, published by OpenLearn, a part of the Open University (OpenLearn, 2010).

State of the Art

Category	Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
Description	Information Gathering	Confirming	Making use of knowledge	Taking apart	Putting together	Judging outcomes
The skills demonstrated at this level are those of	<ul style="list-style-type: none"> • Observation and recall of information; • Knowledge of dates, events, places; • Knowledge of major events; • Mastery of subject matter. 	<ul style="list-style-type: none"> • Understanding information; • Grasping meaning • Translating knowledge into a new context; • Interpreting facts; • Comparing; • Contrasting; • Inferring causes; • Predicting consequences. 	<ul style="list-style-type: none"> • Using information; • Using methods, concepts, theories in new situations; • Solving problems using require skills or knowledge. 	<ul style="list-style-type: none"> • Seeing patterns; • Organisation of parts; • Recognition of hidden meanings; • Identification of components. 	<ul style="list-style-type: none"> • Using old ideas to create new ones; • Generalising from given facts • Relating knowledge from several areas; • Predicting, drawing conclusions. 	<ul style="list-style-type: none"> • Comparing and discriminating between ideas; • Assessing value of presentations; • Making choices based on reasoned argument; • Verifying value of evidence; • Recognising subjectivity.
What the student does	Student recalls of recognizes information, ideas, and principles in the approximate form in which they were learned	Student translates, comprehends of interprets information based on prior learning.	Student selects, transfers, and uses data and principles to complete a problem or task.	Student distinguishes, classifies, and relates the assumptions, hypotheses, evidence, or structure of a statement or question.	Student originates, integrates, and combines ideas into a product, plan or proposal that is new to him or her.	Student appraises, assesses, or critiques on a basis of specific standards and criteria.

Table 3 Recreation of "Bloom's Taxonomy in practice". Published by OpenLearn (2010) (Part 1 of 2)

State of the Art

ample trigger words:	· define	· predict	· apply	· separate	· combine	· decide
	· list	· estimate	· demonstrate	· order	· integrate	· test
	· label	· differentiate	· complete	· explain	· rearrange	· measure
	· name	· extend	· illustrate3	· connect	· substitute	· judge
	· identify	· summarize	· show	· divide	· plan	· explain
	· repeat	· describe	· examine	· compare	· create	· compare
	· who	· interpret	· modify	· select	· design	· summarize
	· what	· discuss	· relate	· explain	· prepare	· assess
	· when	· extend	· change	· infer	· compose	· justify
	· where	· contrast	· classify discover	· arrange	· modify	· discriminate
	· tell	· distinguish	· use	· classify	· create	· convince
	· describe	· discuss	· compute	· analyse	· design	· conclude
	· collect	· explain	· solve	· categorize	· hypothesize	· select
	· examine	· paraphrase	· construct	· compare	· develop	· rank
	· tabulate	· illustrate	· calculate	· contrast	· formulate	· predict
	· quote	· compare		· extract	· rewrite	· argue

Table 4 Recreation of "Bloom's Taxonomy in practice". Published by OpenLearn (2010) (Part 2 of 2)

The taxonomy was revised by Anderson et al. (2001). The main revisions split the taxonomy into a two-dimensional “Taxonomy Table”, with a knowledge dimension and a cognitive process dimension. Some categories were expanded and renamed (“Application”, “Analysis” and “Evaluation” became “Apply”, “Analyze” and “Evaluate” respectively). “Evaluate” changed places with “Synthesis” and became “Create”. While sensitivities to the “versions” of the taxonomy may be helpful to teachers evaluating the values of ILOs, this resolution is outside the scope this work and either taxonomy can be used as a source for ILO verbs. Future work may call for the precision afforded by the revised taxonomy.

2.2.4 ILO Subject Matter

Capability verbs and subject matter descriptors can be drawn from Merrill’s Component Display Theory (CDT) (Merrill, 1983).

Merrill introduces four levels of capability: Remember-Instance, Remember-Generality, Use, and Find. Merrill’s CDT also offers a taxonomy for categorising subject matter, as one of four types: Fact, Concept, Principle and Procedure. The capabilities and subject matter types are brought together in the “Performance Content Matrix”.

Find				
Use				
Remember Generality				
Remember Instance				
	Fact	Concept	Principle	Procedure

Figure 16 The Performance-Content Matrix (Merrill, 1983, p. 112)

Facts consist of two objects and a relationship.

A fact carries no connotations of understanding. A teacher could tell a student that the symbol 囊 is pronounced ‘nang’. The student would associate the symbol to the pronunciation ‘nang’, but needn’t have any conception of what it means. The teacher

has taught a fact. This lack of context or implication means a fact can only be remembered, it cannot be used or found.

By assembling a number of related facts, a concept is constructed. A concept has meaning and is often represented as a concept map. If the teacher were to tell the student that 囊 is pronounced ‘nang’ in Chinese, and that 囊 is a type of Chinese pita bread, then the teacher is teaching a concept.

A principle represents a cause and effect relationship – the principle of gravity, the principle of conservation of energy. They can take the verbal form of “if *this* then *that*”, and sometimes are represented by a formula such as $F=ma$.

A procedure is an algorithm for achieving some goal. It can be represented as a set of steps.

This section has covered sample useful taxonomies for writing ILOs. The next section discusses structuring ILOs.

2.2.5 Structuring ILOs

This section discusses how intended learning outcomes can be decomposed into their constituent ILOs. This process yields a sub-structure of ILOs that support the original, which is the top-level ILO of its sub-structure.

An ILO can be broken down into other ILOs. These “sub” ILOs are the pedagogical enablers of the original ILO, and thus are labelled “enabling” ILOs. The enablement relationship asserts that, if Y enables Z, then Y is probably antecedent to Z. This means that student achievement of ILO Y is a probable prerequisite of achieving Z.

Starting with the ILO “Solve Simultaneous Equations”, and assuming the use of the method of substitution to solve the equations, the ILO entails the enabling ILOs shown in Figure 5.

Solve Simultaneous Equations

- Substitute Variables
- Rearrange Equations
- Balance Equations
- Perform Multiplication
- Perform Addition
- Perform Division

- Perform Subtraction

Figure 17 Flat list of enabling outcomes for "Solve Simultaneous Equations"

The enabling ILOs form a one-dimensional list. However, there are dependencies between some of the ILOs; this is the enablement relation. The list may be restructured to display these relationships:

Solve Simultaneous Equations

- Substitute Variables
- Rearrange Equations
 - Balance Equations
 - Perform Multiplication
 - Perform Addition
 - Perform Division
 - Perform Subtraction

Figure 18 Multi-level list of enabling outcomes for "Solve Simultaneous Equations"

In graph form, each ILO can be represented by a node, and the edges show enablement relations. The resulting network is shown in Figure 7.

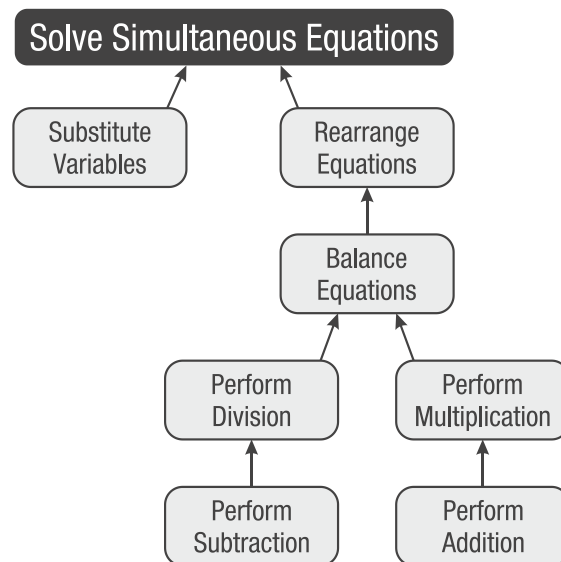


Figure 19 Enabling ILOs for "Solve Simultaneous Equations"

This structure is similar to those used in KST (see section 2.2.1.3). Albert, Nussbaumer, & Steiner (2008) show an extension of KST: Competence Based

Knowledge Space Theory (CbKST). The authors use CbKST to represent subject areas and learner models within a well-defined framework. The iClass project introduced in their research shows an implementation of a CbKST structure as a Hasse diagram.

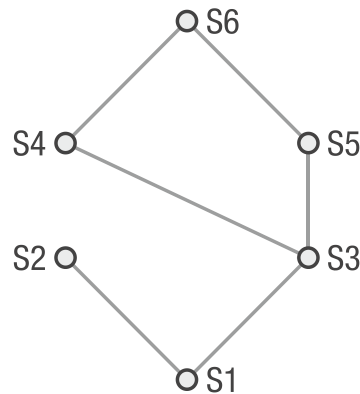


Figure 20 Reproduced figure of “Structure on skills illustrated as Hasse diagram” (Albert et al., 2008)

The Hasse diagram is a mathematical model of a partially ordered set. In-depth exploration of the mathematics implied in the Hasse diagram is outside the scope of this project. When addressing “skills” as in Figure 20, it is sufficient to state that the Hasse diagram implies that each skill (S) is enabled by skills geometrically lower on the diagram, enables those geometrically higher, and that a transitive relationship is in effect. That is, for example, S1 is an enabling skill for S5.

An ILO can be decomposed into its enabling ILOs. The same process can be applied to the resulting enabling ILOs recursively. Solving simultaneous equations is enabled by performing multiplication, which is enabled by performing addition, which is enabled by counting units, which is enabled by sequencing, and so on. This process could potentially be applied infinitely. Practitioners must impose a limit for practicality. Here, we do not suggest a specific limit, but suggest that decomposition is sufficiently extensive when stakeholder consensus declares it acceptable.

In addition to issues with the extent of decomposition, practitioners must decide a tolerable balance between ILO ambiguity and specificity. In this work, ILOs are human-readable, but formalised and encoded such that they can be stored and

manipulated digitally. The content of an ILO can be modelled as objects and fields, and ILOs can be linked with enablement relations, but interpretation of the content remains a role of human users. Given the wide variance in human interpretation, there is inherent tolerance of ambiguity; there is more than one way to skin a cat, de-fur a feline, or barber a moggy.

In section 3.2.3.1, methods for more rigorously specifying ILOs are explored, such as the addition of constraints on time, context, methods and equipment. In this work, a definition governed by marginal utility is in effect. An ILO has reached an acceptable level of ambiguity when the stakeholders agree that the ILO acceptably describes the intended outcome. Conditions and context can be added until all stakeholders agree on a working definition of the behaviour.

This section has introduced the process of decomposing ILOs into their constituent, enabling ILOs. ILOs can potentially be infinitely decomposed, with each enabling ILO decomposed into its enabling ILOs. This chain can be represented as a graph, forming a network of interrelated ILOs. The next section leaves theoretical definitions and relations behind, and explores issues raised against the use of ILOs in contemporary education.

2.2.6 Issues with ILOs

This section illustrates some of the criticism directed towards the use of intended learning outcomes.

Several academics "have serious misgivings" concerning outcome-based approaches to education. As such, the Higher Education Academy have seen it necessary to issue advice on how to implement objective based education "as painlessly as possible." (Overton, 2005)

Hussey & Smith (Hussey & Smith, 2002), introduce their viewpoint that learning outcomes have become prevalent in education, but also in management and audit, which has had negative effects on teaching practice. They insinuate that education is now a commodity to be bought with units of assessment, and the process of such education has been made measurable. In order to be useful, LOs must "specify knowledge, understanding, skills and abilities, rather than simple behavioural responses". The authors believe that knowledge of what a LO means is "parasitic" on that knowledge itself. This point is discussed in 2.4.2. In addition, they argue that

tightly defined learning outcomes do not allow for positive emergent learning outcomes to be embraced by teachers or learners.

This opinion is mirrored by a different Smith (2011) . Smith's work focusses on competences (covered in Appendix D) but the premise is similar to that of Hussey and Smith. Smith argues that reduction and atomisation of learning a topic prevents instructors and students from fully appreciating the topic as a whole. He argues that education should not be reduced to a "tick box" exercise. In the article the author attempts to convince the reader that there are fundamental philosophical differences between competences and competencies. The author argues that those in the field have lost sight of the nobler purpose of education, to better the person, and have become wrapped in simply ticking boxes and focusing on activities that a person can do.

Brousseau (1984) approaches the tick-box culture from a different angle, saying that the use of ILOs leads students to go 'through the motions' without understanding the content.

(...)the more explicit I am about the behavior I wish my students to display, the more likely it is that they will display the behavior without recourse to the understanding which the behavior is meant to indicate; that is, the more likely they will take the form for the substance.

This section has explored some practical and ideological issues with learning outcomes. These criticisms are discussed further in section 3.2.4. The next section investigates contemporary support of ILOs.

2.2.7 Benefits of ILOs

Despite the criticisms discussed in 2.2.6, ILOs remain in use in contemporary practice. This section shows some applications for ILOs.

The University of Southampton (University of Southampton, n.d.) uses ILOs to inform students of the intentions of a course, so that they can make an informed decision as whether or not to subscribe to it. The University claims that articulating outcomes enables students to take responsibility for their learning during the course.

Other sources point towards the benefits seen from the act of formalising the learning outcomes, such as "promot[ing] the development of a coherent learning programme",

guiding students during their studies, and showing how taught modules contribute to the overall teaching aims (University of Cambridge, n.d.).

Achieving common definitions can be important. The lack of common definitions for ILOs and competences has deeper impact than academics quarrelling over semantics. Kunzman and Schmit (2006) revealed the problems caused by nursing professionals not having common vocabulary for what they know or can do, even within their own domain. Once a common vocabulary was introduced, the discussions in the research project they were carrying out became more constructive. The study indicates that the beneficial impact of being able to unambiguously specify behaviour should not be underestimated.

2.2.8 Summary

This section has explored intended learning outcomes, their definitions in the literature and their definition within this work. Supporting taxonomies have been explored, and the process of decomposing ILOs into their enabling ILOs has been discussed. The section ended with a survey of criticisms regarding the use of ILOs and a survey of contemporary uses of ILOs. The next section concerns self-directed learners.

2.3 The Self-Directed Learner

This section discusses what self-directed learning (SDL) is, and what it means to be a self-directed learner. Self-directed learning takes place in nearly all instances of learning, and its place within the traditional classroom is highlighted.

A self-directed learner is someone who engages in self-directed learning. Self-directed learning is captured in other labels, such as self-regulated learning, and has many definitions across the literature.

By self-regulated learning strategy we mean actions directed at acquiring information or skill that involve agency, purpose (goals), and instrumentality self-perceptions by a learner

(Zimmerman & Pons, 1986)

In essence, SDL is seen as any study form in which the individuals have primary responsibility of planning, implementing, and even evaluating the effort.

(Hiemstra, 1994, p. 9)

SDL is any increase in knowledge, skill, accomplishment, or personal development that an individual selects and brings about by his or her own efforts using any method in any circumstances at any time

(Gibbons, 2003, p. 2)

In this work, a self-directed learner is defined as a learner who is intentionally engaging in learning and teaching themselves, at a granularity of a learning transaction or larger (see section 2.1.3).

Self-directed learning is a well-established concept, playing a key role in the lives of historical scholars such as Socrates, Pate and Aristotle (Hiemstra, 1994). Attention has been drawn to other notable individuals such as Benjamin Franklin (Zimmerman, 1990), but anyone who has taught themselves without another human's directed and intentional interference (teaching) has been a self-directed learner.

Self-direction is generally considered beneficial for the learner and the education system, both practically and ideologically. John Gardner, former Secretary of Health, Education and Welfare in the USA, wrote in his book, *Self Renewal*:

[...] the ultimate goal of the education system is to shift to the individual the burden of pursuing his own education.

(Gardner, 1963)

Research suggests self-regulated learners have characteristics that show motivational processes, self-regulation processes and self-orientated feedback loops (Zimmerman, 1990). Zimmerman's prior research shows that these characteristics were strongly associated with higher academic testing levels (Zimmerman & Pons, 1986). McLoughlin & Lee (2010) stress that they consider self-regulated learning as important in the future of education.

Self-directed learning does not necessarily imply isolation, and likely takes place in most traditional teaching scenarios. Hiemstra (1994) describes self-direction as a "continuum of characteristics that exist to some degree in every person and learning situation." He elaborates that self-direction is not necessarily an isolated, solitary pursuit, and lists effective roles for teachers to support learners, such as "dialogue with learner, securing resources, evaluating outcomes, and promoting critical thinking".

Sequencing what the student learns next may also be considered a teacher role. The next section shows the difficulties faced by self-directed learners in routing through content.

2.4 Routing

Routing, the act of sequencing ILOs in a pedagogically logical order, is a challenge for self-directed learners. This section discusses how routing is traditionally performed by teachers, or teaching agents, like textbooks. Whilst learners can take on the teacher roles of the learning transaction, they are not equipped to route themselves. Analogies drawn from the areas of minimally guided pedagogies and adaptive hypertext illustrate this, and the implications of content ordering are discussed.

The next section examines in more detail how routing relates to the teacher role in the learning transaction.

2.4.1 The Teacher Sets the Route

Routing refers to the presentation order of learning transactions, and this is typically undertaken by the teacher. Section 2.1 explored the teacher and learner roles within the learning transaction. The learning transaction addresses a purpose, expressed as an ILO, represented by the encompassing circle in Figure 12 (reproduced in Figure 21).

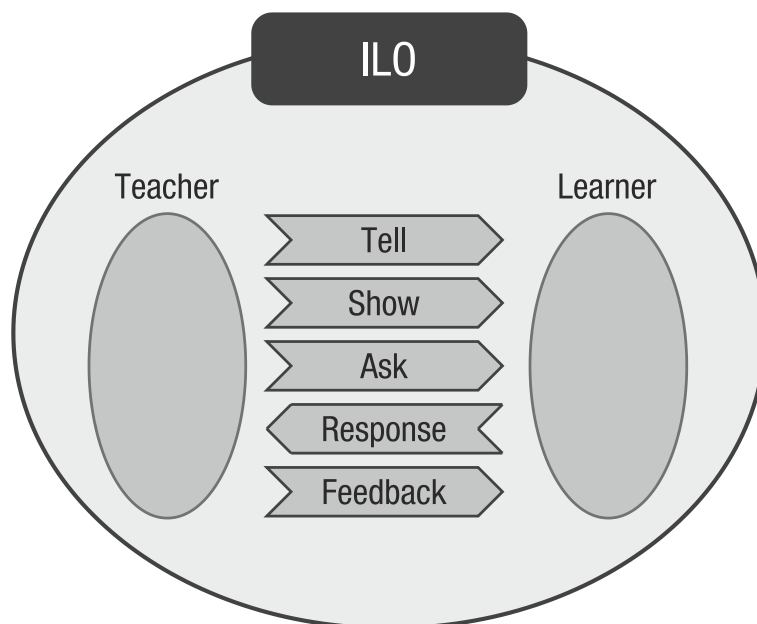


Figure 21 Learning Transaction adapted from (Gilbert & Gale, 2007)

A contemporary school lesson may involve many learning transactions, carried out in a pedagogically appropriate order. In theory, that should mean a learner is taught something only if the learner has acquired the capabilities required in order to achieve the current transaction's objective. The same is true of the content of textbooks and other pedagogically appropriate teaching resources: the sequence of content should be such that enabling content is presented prior to the content it enables. This order is called a route, and routing is performed by the teacher or captured within a teaching resource like a text book. In the case of a textbook, the routing is implicitly undertaken by author.

In essence, some curricula or course specifications are routes. Johnson (1967) defines a curriculum as "a structured series of intended learning outcomes". Textual representations at the fine granularity and specificity of intended learning outcomes examined here are not prevalent in the literature. Typically, this ordering of atomic outcomes appears to remain the purview of the teacher and is not written down.

The teaching order is necessarily set by the teacher or teaching resource author, because logically the order must be specified by someone with both knowledge of the intended learning outcome, *and* knowledge of the enabling capabilities. An additional task can therefore be added to the role of teacher, the task of setting the purpose for the learning transaction, and for the next transaction, and so on. This sequencing of learning outcomes parallels the idea of choosing a route between landmarks on map.

One of the teacher roles in the learning transaction is providing feedback. Hattie and Temperly (2007) discuss the routing aspects of feedback. Feedback should address learning goals, present performance and *direction for future study*. Berlanga (2011) points out the labour intensiveness of providing such feedback, discussing the variation in targets, abilities and backgrounds of the students.

This section has introduced the concept of routing. The task of routing normally falls to a teacher or to the authors of teaching resources. This additional teacher role of routing has implications for self-directed learners, as learners do not know the content area, may not have a map, and, being teacher-less, lack a guide. The next section further explores the problems in routing faced by self-directed learners.

2.4.2 Self-Directed Learners Can't Easily Route

When undertaking self-directed learning, learners fill the roles of both learner and teacher. The learner uses a resource to fill the show & tell aspects of the learning transaction, and implicitly asks and gives feedback on their own understanding.

However, the task of choosing the purpose of the transaction, that is, choosing the next ILO to achieve, is not a task that the self-directed learner is particularly well equipped to undertake. A learner is unlikely to be capable of choosing appropriate intermediate learning goals if they do not know what enabling outcomes are required to achieve their goal. Hussy and Smith (2002) captured this when stating that knowledge of what a learning outcome means is “parasitic” on that knowledge itself.

There is support for the position that the requirement for prior knowledge of a learning outcome to understand its meaning impedes self-directed learners. When discussing students making decisions about their learning, Zimmerman’s research (1990) showed that there was a high cognitive load associated with monitoring one’s own learning outcomes. McLoughlin (2010) states that self-regulated students need to be supported with tools and resources to scaffold their learning.

Self-directed learners are not well equipped with the subject-area knowledge required to effectively route themselves. Further exploration of these difficulties in the context of minimal guidance pedagogies is explored in the next section.

2.4.3 The analogy with Minimal Guidance and Adaptive Hypermedia

The previous section discusses why self-directed learners are ill-equipped to plan the order in which to learn new content. Self-directed learners face the challenge of planning their learning with no oversight. Similar criticisms are levelled at minimal guidance pedagogies.

Minimal guidance pedagogies come labelled with names such as “discovery learning”, “problem-based learning”, “inquiry learning”, “experiential learning”, and “constructivist learning”. These share the characteristics of placing learners in a learning situation and asking them to discover information and principles for themselves (P A Kirschner, Sweller, & Clark, 2006)

Compared with instruction that is strongly guided, Kirschner, Sweller & Clark (2006) claim that “minimally guided instruction is less effective and less efficient” (p. 1). They justify their claim by explaining how learners use their short-term memory in the situations of directed instruction and minimally guided instruction. Kirschner et al. accuse minimally guided instructional approaches to be at odds with conventional understanding about how humans think and learn.

The authors state “All problem-based searching makes heavy demands on working memory” (p. 4). In minimally guided situations, the learner is preoccupied with self-guidance, and has fewer cognitive resources to spend on learning content. In directed instructional situations, the learner is able to devote more resources to tackling the information in front of them.

Charney, Reder, & Kusbit (1990) observed poor performance from minimally guided students. They attribute the poor performance of their “exploratory learners group” to the learners’ “minimal prior knowledge of the domain” (p. 16). The authors describe two phases in discovery learning - “problem formation” and “problem solving”. Problem formation refers to the act of setting up a challenge to solve with the skills they plan to learn. This is correspondent to inventing the purpose and the “ask” within the learning transaction. Charney et al state “These learners may have trouble fully exploring the domain because inexperience prevents them from setting appropriate problem goals” (p. 16).

Kirschner et al. suggest that as learners gain competence, the advantage of direct guidance over minimal guidance diminishes. However, this advantage only diminishes once the learners are sufficiently comfortable with the area and the “guidance” becomes self-generated.

Similar issues around guidance arise in the area of hypermedia. Hypermedia is an application of hypertext which links information in multi-media data in order to facilitate access and manipulation of the information (Lowe & Hall, 1999).

Hammond describes pitfalls that unstructured exploration through a hypermedia system can hold with a comparison to a “stranger in a foreign city without a map” (1989). The problems identified are users getting lost, difficulty in gaining an overview, difficulty in finding their way to a specific resource, users “rambling” in an inefficient manner and finally, interface issues. Kaplan (1993) alludes to users getting lost or finding the array of options overwhelming. The concept of being “lost in hypertext” is also expanded on by Brusilovsky (1996).

Adaptive hypermedia adds a user model in order to tailor the output of the hypertext system to the characteristics and needs of the learner (Peter Brusilovsky, 1999), thereby attempting to avoid some of the issues discussed above. Approaches to determining how to adapt hypermedia are most frequently based on “prerequisite” relations (De Bra, Aroyo, & Christea, 2004). This kind of relationship is described under the label of “enablement relation” in Section 3.2.3.2, and in brief, describes the approach that if X is a prerequisite for Y, then X should be known, or at least introduced, before Y is introduced. Adaptive hypermedia typically makes use of showing, hiding, annotating and highlighting links and content. This is a form of routing according to a user model.

The system proposed in 1.2 shares concepts in AEH, most notably, the notion of prerequisites. These are used for routing in similar ways to those prevalent in AEH.

This section has discussed issues faced by students being instructed with minimally guided pedagogies and users of adaptive hypermedia. These areas are analogous to self-directed learners learning new content, and issues faced by individuals in the former apply to learners in the latter. The work presented in this thesis aims to ease or overcome these issues for self-directed learners. The next section explores the impact that content order can have on learners.

2.4.4 Why does order matter?

Routing refers to the order in which ILOs are taught. Teaching order is important in terms of pedagogical logic; teaching enabling ILOs before those that they enable. Optimisation of these orderings is the subject of some research (Leach & Scott, 2002).

Teaching order can have effects on learning, in terms of cognitive structures formed, and how working memory is used (Kirschner, Sweller & Clark, 2006) (Reid, 2008). Rudnitsky & Posner (1976) indicate that the order of content affects the cognitive structures of understanding that students build. Their experiment indicated that the cognitive structures constructed by their students are similar to the ordering of presentations the students received. They report no increase in retention or test scores within the context of their experiment, but teaching order may have other undiscovered impact.

Prescribing a fixed order to be followed by all learners is unhelpful, as learners have different needs. Johnstone (1993) claims that prescriptive sequencing is useful for

teaching, but not for learning, as differing student abilities means some students leap over sub-concepts that were thought to be essential in their subject.

2.4.5 Summary

Routing is the practice of sequencing ILOs for learners. Teachers generate these routes in classroom settings, and routes are sometimes captured in the structure of textbooks and other teaching resources. Curricula can be considered a basic representation of a route, and the route a student is led along can have implications for how and what students learn. Routing requires prior knowledge of the subject domain, and this requirement precludes self-directed learners from effectively routing themselves.

2.5 Similar technologies and specifications

ILOs capture specific “atomic” learning transaction purposes. Many teaching approaches and technologies have employed the technique of expressing and using these small outcomes, but not necessarily under the term “Intended Learning Outcome”. This section discusses approaches that share characteristics with the proposals presented here.

2.5.1 Teaching Machines

The concept of small learning transactions was used in teaching machines: boxes made of wood or metal containing printed questions, typically on paper tape or on a rotating drum. The first teaching machine was demonstrated in 1924 (Benjamin, 1988) and patented in 1928 by Sidney Pressey (1928). Psychologist B.F. Skinner’s work on teaching machines overlapped and succeeded Pressey’s (Benjamin, 1988). One such machine is shown in Figure 10.

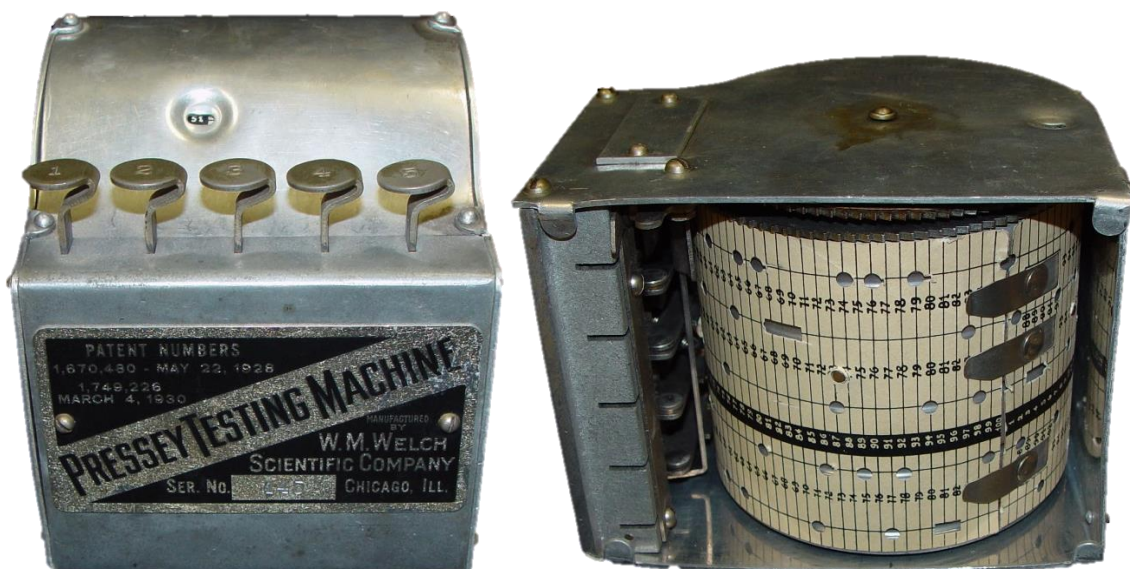


Figure 22 An exemplar teaching machine (labelled “testing machine”), designed by Pressey and manufactured by the W.M. Welch Scientific Company. Image taken and released to public domain by Wikipedia User Gomer Bolstrood, September 2006. Background of image removed for clarity.

The machines operated in various ways. Some had multiple modes, such as test mode or teach mode. Most followed a general pattern of execution: A printed question would show through an aperture in the box. Students answered the question by

arranging levers, writing on a provided answer tape or inserting a stylus into a corresponding slot. They would actuate the machine, typically with a lever or knob. If the machine was in test mode, it would record the student's answer and present the next question. A machine in teaching mode would jam if the answer was incorrect. The student would revise their answer until correct, and then the machine would present the next question. Some machines counted attempts. When using machines that required students to manually write their answer on another paper tape, turning the knob moved their answer under a transparent window (to prevent alterations), revealed the model answer, and the students marked their answer for correctness. Teachers could review the outputs. (Skinner, 1960)

Teaching machines like these were used in Harvard University in the 1960s for teaching psychology theory and other subjects (Holland, 1960).

Whilst discussing teaching machines, Holland introduces the concept of “a careful program of progression” to teach new behaviours, starting from a simple behaviour and building increasingly complex behaviours upon the simple (1960, p. 279). This is analogous to enabling ILOs supporting top level objectives as discussed in 2.2.5.

Teaching machines were arguably the first uses of technology to simulate instruction. The format of small interactions formed a curricula that could be modelled as ILOs. The next section shows some examples of more contemporary curricula of ILOs.

2.5.2 Intelligent Tutoring Systems

Intelligent Tutoring Systems (ITSs) are computer systems designed to mimic the functionalities of human tutors (Corbett, Koedinger, & Anderson, 1997).

Hartley and Sleeman (1973) set out a seminal definition for ITSs, arguing that such systems should have: a knowledge of a domain, a conceptualisation of the learner's knowledge within that domain, and some knowledge of teaching approaches appropriate to the domain. More than 20 years later, Shute & Psotka (1994) claimed that this definition stood unchallenged. Commenting on this triadic definition, Murray (1999) points out that domain models should, by definition, be kept separate from teaching strategies. However, he goes on to claim that it is not possible to make these two components entirely separate, stating that complex relationships between concepts need to be taken into account.

The hypothetical system described in Section 1.2 fits Hartley and Sleeman's ITS definition, and could therefore be considered an instance of an ITS. The ILO network is the domain model, and the learner model is a special, individualised version of the domain model. The routing algorithms constitute some teaching strategy, similar to an ITS. The system proposed is modular. Future work may find that indivisibility between content and teaching models, as Murray claims, impacts on teaching quality.

2.5.3 Curricula using ILOs

The following are illustrative examples of curricula using ILOs.

2.5.3.1 CS2013

The Association of Computer Machinery (ACM) and the Institute of Electrical and Electronic Engineers (IEEE) maintain a curriculum document entitled CS2013 (The Joint Task Force on Computing, 2013) that lists a "Body of Knowledge" for undergraduate Computer Science programs.

A sample of the curriculum concerning the instruction of Object-Orientated Programming is shown in Figure 11.

Learning outcomes:

[Core-Tier1]

1. Design and implement a class. [Usage]
2. Use subclassing to design simple class hierarchies that allow code to be reused for distinct subclasses. [Usage]
3. Correctly reason about control flow in a program using dynamic dispatch. [Usage]
4. Compare and contrast (1) the procedural/functional approach (defining a function for each operation with the function body providing a case for each data variant) and (2) the object-oriented approach (defining a class for each data variant with the class definition providing a method for each operation). Understand both as defining a matrix of operations and variants. [Assessment]

Figure 23 Extract of CS2013 Body of Knowledge for Object Orientated Programming

2.5.3.2 Comprehensive Adult Student Assessment Systems (CASAS)

Comprehensive Adult Student Assessment Systems (CASAS) is the name given to a curriculum and to the organisation that compiled it. CASAS is a non-profit organisation in the USA that focuses on teaching and assessing life and work competencies in adults (CASAS, 2011). Their curriculum of competencies "identify

more than 360 essential life skills that youth and adults need to be functionally competent members of their community, their family and the workforce” (CASAS, 2008).

These skills fall into nine domains including: Basic Communication, Math and Learning and Thinking Skills. CASAS lists both Competencies and Content Standards, where a Competency is a contextualised skill, and a standard is the generic transferable skill required to perform it. For example, Figure 24 shows the relationship between the specific competency of “Select appropriate housing by reading ads, signs, and other information” which requires the performer to carry out the generic standard “Interpret abbreviations in specialized contexts” and to “read basic sight words”.

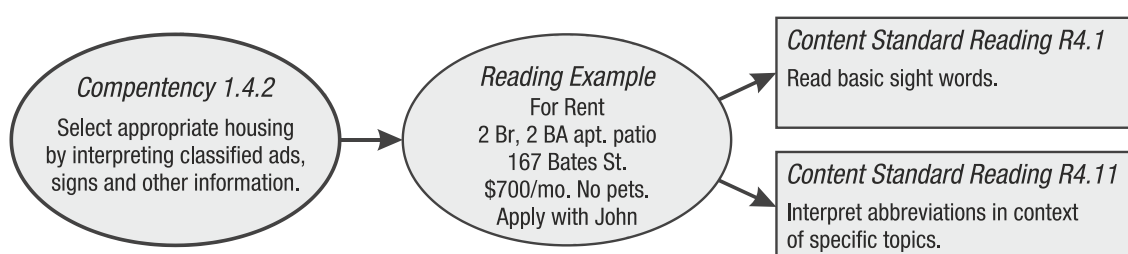


Figure 24 Adapted diagram showing mapping of an example of Reading to Content Standards and a Life Skills Competency (CASAS, 2006)

2.5.3.3 Khan Academy

Khan Academy is a web-based teaching platform, distributing instructional videos and interactive test materials. The organisation was incorporated by Salmond Khan in 2008, though the initial videos were created in 2006 (Khan Academy, n.d.-a). Kahn Academy hosts a tree-like structure that represents the relations between the subject areas covered by the Kahn Academy programme. This structure is shown in Figure 13.

Khan Academy received its largest funding grants from Google and from the Bill & Melinda Gates Foundation in September 2010 (Khan Academy, n.d.-b). Early summary findings by SRI International, an independent research organisation contracted by the Bill & Melinda Gates Foundation to evaluate the impact of Khan Academy in a sample of American schools, show that 91% of teachers involved with the project intended to continue using Khan Academy in their future teaching (SRI International, 2014). SRI reports:

State of the Art

A positive association was found between more Kahn Academy use and more problem sets completed and two outcomes (1) improvements in student test scores, and (2) improvements in three of the four self-reported nonachievement outcomes – math anxiety, math self-concept, and academic efficacy (i.e., belief in one's ability to succeed in academic endeavours).

(SRI International, 2014, p. 12)

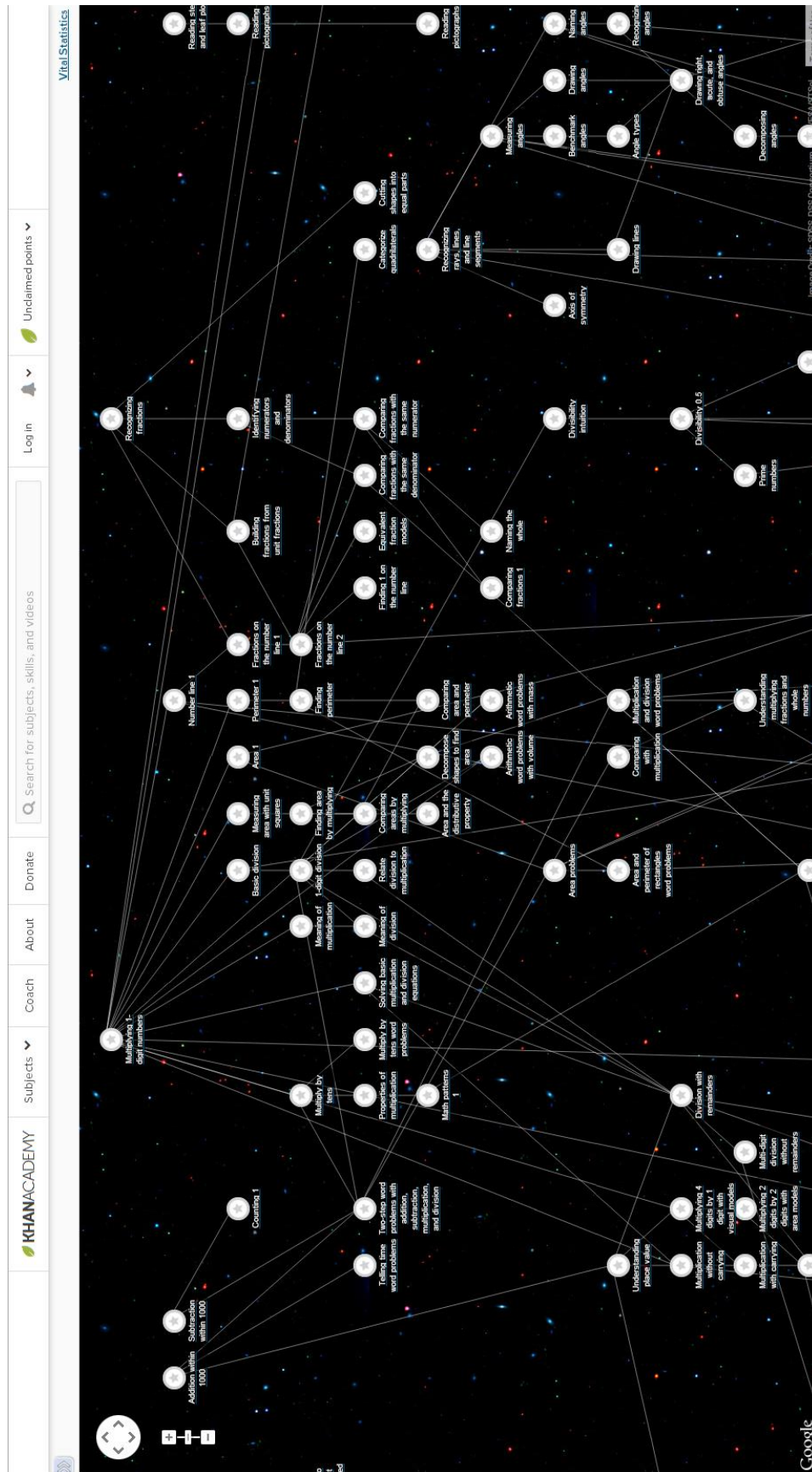


Figure 25 Partial screenshot of Khan Academy's "Knowledge Map". Accessed from <https://www.khanacademy.org/exercisedashboard>, 10th July 2014.

2.5.4 Competencies and Competences

Competencies (and, less frequently, ‘competences’) appear in the research area of ILOs. Like ILOs, there is no single authoritative definition (Sampson & Fytros, 2008). Most descriptions specify that a competence shares the characteristics of an ILO: an observable capability with a subject matter, along with an indication of the context that the performance of the observed capability takes place in. A competence is built upon an ILO, as represented in Figure 26.

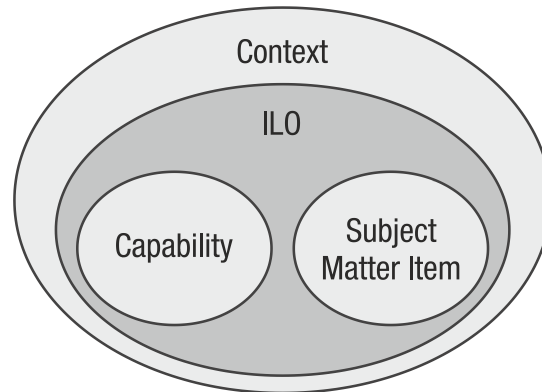


Figure 26 Representation showing how a competence builds upon an ILO

Since a competence contains an ILO, discussions regarding the capability and subject matter items of competences are relevant to this work, even if the ILO parts are not named as an ILO.

Competencies are often explored with the idea of interrelating, or networking amongst themselves. Stoof (2007) states: “In a competence map, curriculum content is described in terms of interrelated competencies rather than in terms of fragmented or dissociated knowledge, skills and attitudes” (p. 3). Stoof discusses surrounding theory of competences in this paper that chronicles the development of a tool to help educators design competences. The paper describes the function of competence maps as a representation of achievements, shown by related competencies.

Additional material regarding competence, including an original context model, is contained in the appendix at Appendix D. Further discussions of context are in section 3.2.3.1.

2.5.5 Learning Objects

Like ILOs, competencies, and competences, Learning Objects lack an authoritative definition.

Cisco Systems states “learning objects are based on a single learning or performance objective, and they are built from a collection of static or interactive content and practice activities” (Cisco Systems, 2003).

The New Media Corporation (NMC), who publish guidance on Learning Objects define them as:

(...)a collection of digital materials — pictures, documents, simulations — coupled with a clear and measurable learning objective or designed to support a learning process.

(Johnson, 2003)

This definition also forms the basis of Smith’s definition (Smith, 2004).

The IEEE Learning Object Metadata (IEEE & IMS Global, 2006) is a model used to describe learning objects and other educational content. The model includes fields such as “purpose” and “description”, drawing from taxonomies that describe subject headings as opposed to capabilities.

Whilst these are not shared definitions throughout the domain, other definitions in use are similar. These definitions indicate the presence of a learning objective, and issues surrounding Learning Objects are shared by ILOs. In section 2.2.5, issues around granularity and specificity of ILOs are discussed. These same issues in Learning Objects are explored by Wiley (2000).

This section has introduced the concept of a Learning Object. Whilst there is no shared definition for a Learning Object, several definitions in contemporary literature include a reference to something like an ILO. Learning Objects are revisited in 3.1.7.3.

2.5.6 IMS Learning Design

IMS Learning Design (IMS LD) is designed to capture learning processes, independently of the pedagogy that those processes are influenced by. The standard uses the analogy of a theatre play, where individuals take ‘roles’, and actions undertaken by the roles are represented by ‘activities’. The activities take place within an ‘environment’, which consists of learning objects and services (IMS Global, 2003a).

These scenarios are modelled in XML, and can be “played” via players such as CopperCore, released by the Open Universiteit Nederland (The Open University in the Netherlands) (“CopperCore: The IMS Learning Design Engine,” 2008).

Sitthisak & Gilbert (2009) claim that IMS LD is too abstract and generalised to be useful in its current form. The main problem with IMS LD identified by the authors is the use of unstructured textual definitions for learning objectives. This free text is too general, and could be misunderstood by educators, making exchanged LD objects useless. The authors propose altering the specification to include ILO's and competences. They suggest differentiating the roles of student and teacher, and introducing a special "evaluation" activity for the teacher, that would result in a "feedback" artefact being provided to the student.

2.6 Summary

This chapter explores the present state of the art in ILOs and related subjects. A major theme of this chapter is that many of the core topics have various definitions. Taken forward is the notion that Learning can be represented by a change in behaviour, and that teaching consists of activities intended to support the learner's change in behaviour. The relationship between these two practices is captured in Gilbert and Gale's (2007) learning transaction. An ILO represents the “purpose” for any given learning transaction.

Taxonomies such as Bloom's Taxonomy of educational objectives and Merrill's Component Display Theory can be used to add rigour and specificity to ILOs. ILOs can be interrelated to create ILO networks.

Self-directed learners are learners that teach themselves. Self-directed learners have to fulfill the teacher role of sequencing ILOs. This is known as routing, and self-directed learners are not well equipped to route themselves through content they are unfamiliar with. This is analogous to learner difficulties in minimally guided pedagogies, and is part of the reason behind the creation of technologies like Adaptive Educational Hypertext.

Some of the first uses of recognisable ILOs came with the teaching machines of the 1930's. Years later, Intelligent Tutoring Systems represented a similar-but-different

approach, with aims of creating comprehensive teaching systems. Several curricula also use outcomes similar to those defined here, such as CS2013 and Khan Academy.

Chapter 3 critiques the contents of this chapter with respect to the ideas explored in the Motivations section at 1.2, and proposes a synthesised system based upon the foundations examined here.

3. ILO Networks and Routing Algorithms

This chapter discusses the literature from Chapter 2, describes a synthesised system based upon the state of the art, and defines the models and paradigms used in such a system.

3.1 Discussion of the State of the Art

This section discusses the state of the art in Chapter 2. The structure of this section broadly corresponds to the structure of Chapter 2, with interrelated topics grouped into sections.

3.1.1 Learning, Teaching and the Learning Transaction

Section 2.1.1 introduces differing definitions of learning. Within this work, the definition used takes the form of “learning is a change of behaviour”, or more specifically, “learning is evidenced by a change in behaviour”. This definition is superficial and observational, and takes no account of neurological, emotional or other human factors in learning. As such, it provides a useful discrete measure for the purposes of this work, but the exclusion of the human factors should not be read as a dismissal of their importance.

Given this definition of learning, the term eLearning is a contradiction. Learning is a measured change in human behaviour, due to a difference in human cognition. Technology does not fit into this definition. Current definitions around eLearning concern delivery mechanisms for presenting teaching materials – mechanisms that fit better under the label of teaching. eLearning can’t exist – but eTeaching does. A framework for an eTeaching system is presented in section 3.2.

The tasks of learning and teaching, and the roles of the learner and the teacher are intertwined. It is necessary to untangle these interacting facets to succinctly model the self-directed learner. To this end, Figure 27 shows a summary of the roles discussed in Section 2.1.2.

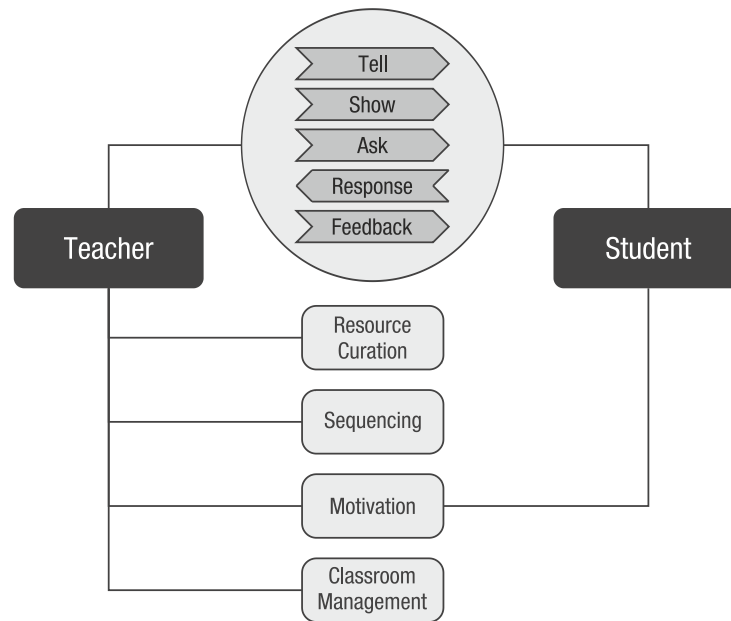


Figure 27 Elaborated roles of teaching and learning with directed learning

Figure 27 shows that the teacher is responsible for the teacher role within the learning transaction, the curation of resources needed to support the learning transaction, the sequencing of learning transactions, extrinsically motivating learners if necessary, and other management and logistical issues regarding the learning environment. The learner is responsible for their part in the learning transaction, and responsible for ensuring their attention and perhaps their intrinsic motivation.

When dealing with a self-directed learner, the situation changes, as shown in Figure 28.

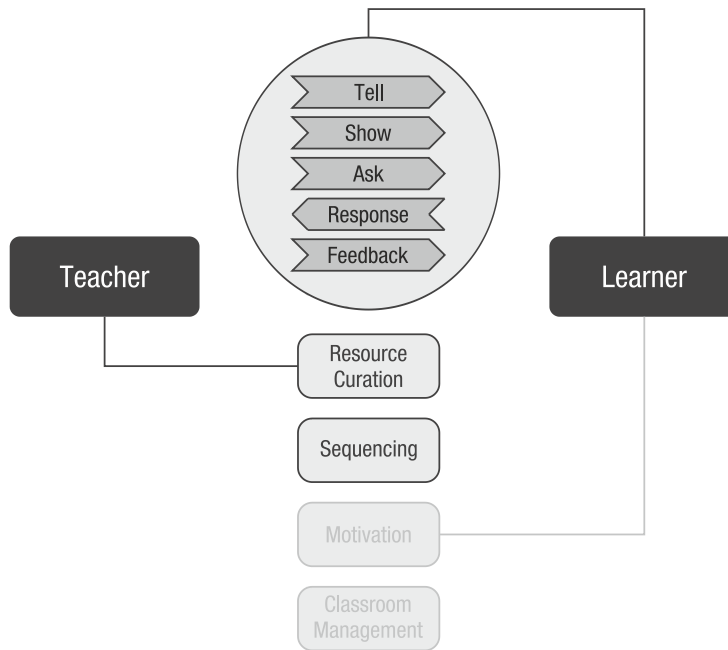


Figure 28 Elaborated roles of teaching and learning with self-directed learning

In Figure 28, the learner is self-directed. They take on responsibility for the whole learning transaction, and for their motivational drive to be a self-directed learner. As the motivational drive to be a self-directed learner is inherent in the definition, motivation and attention is not considered further. Likewise, issues of classroom or peer working are not considered further. Curation of resources to support the ILOs still falls under the remit of the educator. The orphaned necessary facet is sequencing of ILOs, as the self-directed learner is unable to fulfil this role.

3.1.2 ILOs

Section 2.2 introduced pertinent literature surrounding ILOs. This included information about general intended learning outcome definitions, as well as machine processable definitions. ILOs in various machine-processable forms have arguably been in existence for close to a century.

Within these definitions, there are common issues to notice. Firstly, there is no meaningful consensus on what an ILO is, or what it should look like. There are no interoperable templates or specifications further than RDCEO, which, in essence, is a general cataloguing standard rather than one specifically addressing or defining ILOs. Furthermore, the disparate ILO specifications appear myopic – there is seemingly no

anticipation or intention to use the standards for anything but cataloguing ILOs. The existence of HR-XML shows there is a multidisciplinary demand for interoperable and well-defined specifications. The free text description used by HR-XML further shows that difficulties in specifying ILOs is not limited to the domains of pedagogical science.

Further to the drawbacks of the specifications mentioned, there are dangers and drawbacks to the very use of ILOs in general. An ILO specification is a model, and as such, it simplifies reality and omits unhelpful details. Considering an ILO as anything but a simple description of behaviour imbues the model with too much authority. In line with this, it is important to take into account that ILOs are abstract constructs. ILOs describe behaviour without mention of where that behaviour takes place. Human activity does not exist in a vacuum, it is contextualised by setting and situation; an ILO is an abstract model. The addition of context changes an ILO definition into a Competence definition.

The main characteristics of ILOs that afford functionality are that they are discrete, unique and comparable. ILOs give a common language between and within groups of teachers, students and other stakeholders.

3.1.3 Capability Verbs and Subject Matter Types

Sections 2.2.3 and 2.2.4 introduced Bloom's Cognitive Taxonomy and Merrill's CDT respectively. These concepts were included in order to provide controlled vocabularies for the capability and subject matter item descriptions in the system proposed in 3.1.5. A controlled vocabulary is a restricted set of terms designed to specifically and exhaustively specify the concepts within a body of information (Wallace, 2007).

Bloom's Cognitive Taxonomy and Merrill's CDT, and their derivatives, are the most prevalent in the literature. However, the use of such specifications comes with drawbacks.

From the author's own experience, it can be difficult to classify a behaviour to a level, or a subject matter to a type. Frequently the cause of these difficulties arises from a misunderstanding or under-development of the conceptual meaning of the ILO. This can take the form of confusing the ILO with the subject matter, failing to describe the subject matter properly, or wrestling with an ILO that is conceptually too large and would be better decomposed into a top-level objective with one or more enabling objectives.

In addition, some may consider the taxonomies inadequately detailed to represent the subtleties of some educational outcomes.

However, such taxonomies form the basis of the common language used to discuss pedagogy today, and are instrumental in the model proposed here.

Merrill addressed optimal teaching strategies for each capability/subject-matter mapping. In addition to being a useful component in the model, the inclusion of subject matter types may allow future development in subject-matter targeted teaching methods.

3.1.4 ILO Networks and KST

Section 2.2.5 discussed how ILOs can be decomposed and formed into networks.

By creating directed networks of ILOs, it is proposed that non-subject matter experts can route though content unfamiliar to them. The literature found did not show any experiments in this area. As yet, the “routability” of such networks remains theoretical.

There are no established protocols for the proper construction of ILO networks. Therefore, it is not possible to formally verify the ILO networks herein.

At present, the evaluation is solely a manual endeavour and subject to human error. Any experimental implementations are at risk of evaluating learners with an inaccurate or incomplete network. In the future, it may be possible to automate or semi-automate aspects of network verification. This is discussed further in section 1.2.4.4.

KST is the most similar specification to that which is proposed here. KST maps problems, in the form of test items (questions), and the enablement relationships between them. This is arguably an easier way to represent educational achievement – “a learner can answer a question correctly”, as opposed to “a learner can display this behaviour”. An additional advantage of modelling problems is conferred by the fact they could be defined with a “correct answer”, likely allowing consensus on problem meaning to be achieved more easily.

However, it is not clear that KST may not be a scalable system. KST depends upon the creation and connection of many distinct questions. The surveyed literature did not reveal whether KST can support changes in granularity and no information was found regarding grouping of problems in large problem spaces. ILO Networks, in

contrast, can be considered at differing levels of granularity. Several ILOs at a fine granularity compose single ILOs at a coarser granularity.

KST is a mathematical model and offers a technically defined specification. However, the precise mathematical notation and terminology used in KST may render the specification inaccessible to the majority of educators who could otherwise benefit from it. In the future, it may be possible to link or derive ILO networks from subject matter networks or from KST problem maps, affording the benefits of KSTs specificity to a more approachable user view.

3.1.5 Benefits and Drawbacks of ILOs

Sections 2.2.6 and 2.2.7 discussed literature describing positive and negative implications surrounding the use of ILOs.

The arguments presented by Overton (2005), Hussey and Smith (2002), and Smith (2011) against ILOs place particular emphasis on misuse of ILOs, either by other teachers, or by administrators or other stakeholders using ILOs as a sole measure of teacher and learner performance. Other detractors accuse outcome-informed approaches of compartmentalising a subject area to the point where overview is not possible. Brousseau (1984) explains his perception that students working with ILOs simply perform the prescribed behaviours at a surface level, progressing from one discrete achievement to the next, without appreciation of the whole subject, which is a view supported by Smith (2011). This contrasts with Cambridge University's use of outcomes in order to display and explain the coherence of their individual modules within a course.

The arguments are not strictly associated with the concept of ILOs. The same criticisms of over-focus on audit, or learning compartmentalisation could be levelled against standardised testing, or teaching with textbooks. Both practices separate a subject into questions, paragraphs or pages. ILOs could be used in the same way, but in these criticisms, it is the use in question, not the ILO-informed systems themselves. The detractors also fail to take into account the study of subjects solely undertaken for accreditation purposes. Arguably, there is little surrounding subject matter when considering company policies, printer servicing, or health and safety briefings.

Hussey and Smith (2002) claim that tightly defined outcomes prevent teachers from diverging from lesson plans in order to follow students' related interests. However, it seems logical that, with a sufficiently comprehensive ILO network, a teacher could

follow student interests and record those achievements as opposed to those they had perhaps planned. In this regard, the teacher would actually have far more freedom to customise lessons to the students' interests than otherwise afforded. If the network did not contain ILOs representing the student interest, the teacher may look to improve the network for the benefit of future students, or classify the interests as so far divergent from the topic studied as to be an ineffective use of classroom time.

The voices in support of ILOs focus on how ILOs facilitate communication – the University of Southampton uses the outcomes of their course descriptions to support students in making informed choices about which courses and modules to pursue. Kunzman and Schmit (2006) reported that they found the need to build a “competency catalogue” (p 5) in order to effectively facilitate discussions between healthcare professionals. This thesis argues that the potential applications of ILO-informed systems far exceeds these narrow benefits, as detailed in section 1.2.

3.1.6 Self-Directed Learning and Routing

Sections 2.3 and 2.4 examine the definition of a self-directed learner and the issues self-directed learners face when sequencing intended learning outcomes. When assuming an ILO-informed system, this sequencing is called routing. This thesis argues that self-directed learners would benefit from support in routing.

A stereotypical teaching scenario involves a teacher standing at the front of a class, and instructing learners in content and in activities. In the periods where the teacher is speaking to the whole class, the show and tell operations of the learning transaction are performed by the teacher, and the learner provides the “ask” implicitly, possibly taking the form of: “Do I understand this? Does this fit with what I know already?” The learner also generates feedback (“I understand this. This is coherent with what I know already.”) In this way, the student is engaging in self-directed learning within a traditional teaching environment.

In fact, it is possible to go so far as to state that most of the learning in the classroom/lecture context is actually self-directed. Under the definition of self-directed learning presented in 2.1.1, if a student is learning from a textbook, they are engaging in self-directed learning, even if the teacher is in the room and even if the teacher instructed them to read it.

From this viewpoint, entirely directed instruction only comes when a teacher is fulfilling all of the show, tell, ask and feedback operations within the learning transaction, most intensely in a one-to-one tutoring arrangement.

This section situated self-directed learning within classic classroom teaching scenarios. Self-directed learning can be seen to be the main instructional method in a classroom, even within a teacher-centric pedagogy.

When considering self-directed learners outwith the classroom situation, truly independent self-directed learners, issues arise regarding routing. These issues are analogous to those associated with minimal guided pedagogies. Self-directed learners struggle with “problem formation”, that is, determining of all the ways they could apply or use information as discussed by Charney, Reder, & Kusbit (1990). Self-directed learners are faced with the challenge of forming problems with subject matter they do not yet fully understand. This thesis proposes ILO networks and routing algorithms to support self-directed learners in this teaching aspect.

3.1.7 State of the Art in ILO Specifications and Systems

This section discusses specifications of ILO-like systems and related models.

3.1.7.1 Implementations and Specifications

Section 2.5 shows examples of specifications and systems that use concepts similar to those proposed here.

Pressey’s and Skinner’s teaching machines show that ILO-type thinking has existed for some time. These machines, based on questions and answers, may be considered closer to the paradigms of KST, but the principle of decomposing complex problems or behaviours remains the same.

The IEEE and ACM’s CS2013 (Computer Science 2013) curriculum is shown as a typical example of a large and relatively developed curriculum. These outcomes describe behaviours, but may not be helpful to self-directed learners as the document is directed towards institutional courses focused on large cohorts of learners.

In contrast to the complex academic subject matter and capabilities represented in CS2013, the CASAS outcomes exemplify a curriculum of learning outcomes with a more vocational focus. This shows that ILOs are applicable for a variety of learning goals. The subject areas such as “understand how to manage household finances”

and “understand consumer protection measures” (CASAS, 2008, p. 6) are representative of subjects where education is a mostly functional undertaking. Critics of ILOs discussed in 3.1.5 accuse ILOs of stripping the holistic “big picture” view of subject areas; CASAS competencies address functional areas that are essential to contemporary living yet probably undeserving of detailed, impassioned study.

Khan Academy is a relatively new organisation, founded in 2006. In 2012, Kahn Academy served approximately 10 million students in a “meaningful way” (Noer, 2012). Khan Academy’s “Knowledge Map” is the most prominent use of a structure similar to the ILO networks proposed here. However, the organisation has published no standards or guidelines regarding how they partition mathematics into the activities and outcomes represented by the nodes. As such, it is not possible to identify what models are used, or how the map is verified. Other academic areas that Khan Academy supports, such as physics, medicine or economics do not appear to have “knowledge maps”.

3.1.7.2 Context

Context refers to the situation and surroundings in which the ILO performance is established. Context was mentioned in relation to competences in section 2.5.4, with Figure 26 (copied below as Figure 29)

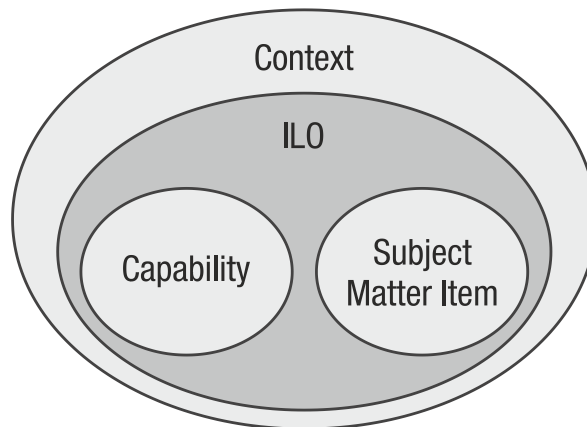


Figure 29 Duplication of Figure 26, showing how a Competence builds upon an ILO.

The specification given for an ILO in section 3.2.3.1 does not include context. However, for many ILOs within the cognitive scope, context is implied. Any ILOs evidenced by assessments take place in an exam hall or a class test setting, and are

contextualised to that limited and fairly reproducible setting. For the models proposed in this work, this implicit contextualisation is considered sufficient. An original context model is shown in Appendix G.

3.1.7.3 Learning Objects and Learning Design

Sections 2.5.5 and 2.5.6 introduced subject areas complementary to ILOs and ILO networks; those of learning objects and learning design.

Learning objects generally refer to resources or resource groupings that are designated for some learning and teaching purpose. IEEE's LOM is one of the most developed of the specifications for describing the meta data of a learning object. Whilst LOM offers many fields to satisfy interoperability requirements, and fields linked to taxonomies that specify subject headings, the LOM model does not accommodate ILO descriptions as described here. Linking ILOs to learning objects and other artefacts may be beneficial, allowing self-directed learners to find resources appropriate to the ILOs they are undertaking.

Learning Design is an IMS standard that models the learning and teaching process in a format similar to a stage play. Learners and teachers undertake roles and pursue activities within an environment. IMS LD does call for optional specification of "learning objectives" (IMS Global, 2003b) and represents them as either user-defined outcomes or outcomes hosted on other sites. A formalised representation of ILOs would fit into IMS LD without the need for refactoring either standard.

3.2 A Synthesised System

This section takes the state of the art described in Section 1 and discussed in 3.1 and synthesises a system that could be used to support self-directed learners. This system provides the context for the research questions presented in Section 3.2.4. The synthesised product, hereafter referred to as the 'ILO System', can be described behaviourally and structurally.

3.2.1 A Behavioural View

This section shows the behaviour that defines the ILO system. In the following use cases, "position" refers to the ILOs the learner has achieved. Table 5 shows a use case for the system.

Table 5 Use case of the ILO System from the learner's point of view

Main Success Scenario (MSS)

1. The learner accesses the teaching system and requests the next ILO.
2. The teaching system suggests the next ILO.
3. The learner marks the ILO as achieved.
4. Items 1-4 are looped until the learner achieves the target ILO.

Extensions

- 1a: Learner has no target ILO recorded.
 1. Learner enters target ILO, returns to MSS at step 2.
- 1b: Learner has no position recorded.
 1. Learner specifies position, returns to MSS at step 2.
- 3a: The ILO achieved is the target ILO.
 1. The system exits the loop.

Figure 30 illustrates this use case.

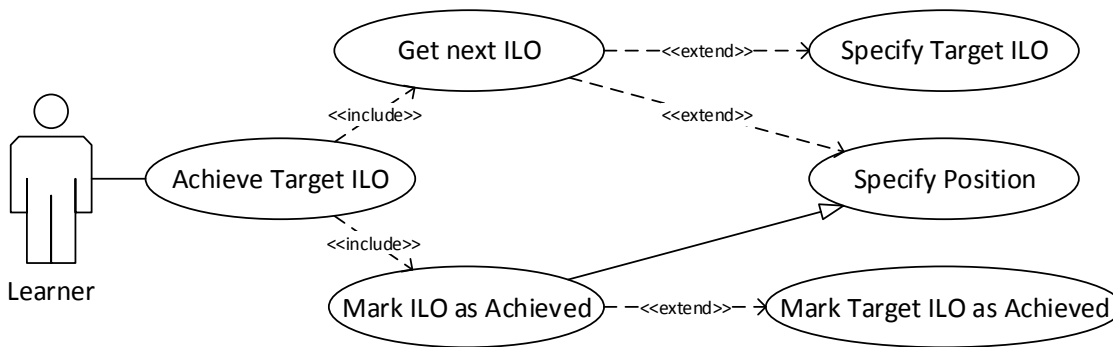


Figure 30 Use case diagram showing learner interactions with the ILO System. Lines labelled <<include>> show a dependence between the source and destination steps. Lines labelled <<extend>> denote conditional included steps. Lines with a hollow arrow head show an inheritance (i.e. kind-of) relation.

Figure 30 shows that the main goal of a learner interacting with the system is to achieve some target ILO. The system returns the next intermediate ILO unless the learner has no target or no position recorded. If this is the case, the learner specifies their target and/or position, and then the system returns the next intermediate ILO. The learner marks the ILO as achieved, thereby updating their position. If the ILO achieved is the target ILO, the system exits the loop, otherwise, the system returns the next intermediate ILO.

This behavioural specification glosses over implementation details, such as how a learner would mark their achievement of an ILO, or how specifically an algorithm would determine the next ILO. Provisional solutions can be found in 3.2.3.3 and a

more comprehensive examination with potential solutions is provided in the future work in section 7.3.

3.2.2 A Structural View

Figure 31 shows the entities involved in the synthesised solution.

Solid filled diamonds ♦ represent composition relationships; an ILO comprises a Subject Matter item and a capability.

An unfilled arrowhead △ represents an inheritance or kind-of relation; a learner model is a kind of ILO network.

An unadorned line represents an association; the learner is associated with the learner model.

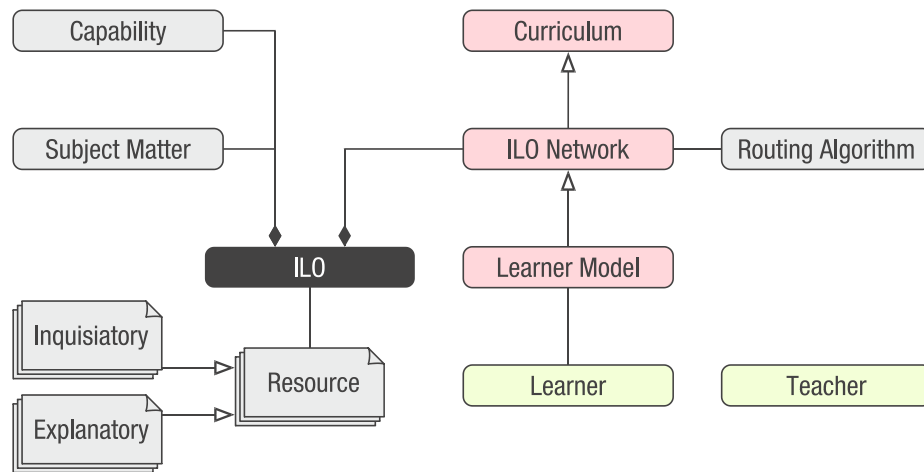


Figure 31 Structural view of a synthesised system

This diagram also includes the following relationships:

An ILO Network is comprised of ILOs.

An ILO Network is a type of Curriculum.

Routing Algorithms are associated with ILO Networks.

A Learner Model is a type of ILO Network.

Resources can be Explanatory (those that ‘show and tell’) or Inquisitory (those that ‘ask’).

Resources are associated with the ILOs that they address.

The Teacher element is not linked to any other element in the diagram, which is unsurprising given that the system is designed for the support of self-directed learners. However, the Teacher could legitimately be linked to any and all of the

elements in the diagram, as the teacher is intended to be the overseer and curator of the whole system, as well as its failover. That is, should the system fail a student, logistically or pedagogically, the human teacher assumes the complete teacher role in the learning transaction.

3.2.3 Proposed Models

The ILO system uses the following models.

3.2.3.1 ILOs

Section 2.2.2 introduced the definition of ILOs used in this work in order to validate the inclusion of ILO Capability Verbs and ILO Subject Matter (sections 2.2.3 and 2.2.4 respectively). The definition introduced stated that an ILO is defined as a capability associated with some subject matter.

For the ILO system, the task of interpreting the ILOs falls to humans and stakeholder consensus. The task of deciding what assessments and associated performances constitute sufficient evidence of achievement of an ILO likewise falls to humans.

As such, elements that strictly prescribe definitions of performance and behaviour are unhelpful, as such aspects are subjectively interpreted. A more productive approach may be to use consensus on suitability of an assessment item as a proxy for consensus on the meaning of an ILO. The problem space model of KST covered in section 2.2.1.3 inspires this approach.

In the proposed model, the following fields are included in the specification of an ILO:

- Id
- Prose
- Bloom Level
- Capability
- Subject Matter

Id gives the ILO a unique identifier, while Prose contains human interpretable text describing the ILO. Both the Capability and the Bloom level to which it belongs are required, as certain verbs can appear on multiple levels, meaning different

performances. Subject matter is represented by one of the four types identified by Merrill and discussed in section 2.2.4.

Just important as what is included in ILOs, is what is omitted. Levels are not included in this model. Several specifications of ILOs call for levels to be assigned – novice, beginner, proficient and expert, or similar. These levels are arbitrarily assigned.

A teenager achieving ILOs in fundamental statistics needs to exhibit the same performances as an adult or a pre-schooler claiming those same outcomes. The ILOs, and therefore the required performances, are immutable regardless of the learner. In such cases of differing learner types, the resources used to teach and assess would probably be different.

Sitthisak, Gilbert, & Davis (2007) rally against arbitrary numerical values assigned to "levels of knowledge". They list out some properties that they believe a "good" specification embodies. Due to their generality and lack of prescription, standards like HRXML (see section 2.2.1.2.1) and IMS RDCEO (see section 2.2.1.2.3) are considered unsuitable for this role.

The ILO system proposes a model that links ILOs with their enablers via an enablement relation. This results in an ILO network. Within this model, the "levels" denoted by other specifications become subnetworks or subsets of nodes on the larger network. Consequently, ambiguous arbitrary "levels" become somewhat meaningless against precise specifications of capabilities.

3.2.3.2 ILO Networks

Any ILO can be decomposed into its enabling ILOs. An ILO can enable more than one superordinate ILO. This means that ILOs can form a network, or more specifically, a directed acyclic graph. The graph is directed because the enablement relation is directed from enabler to enabled. The graph is acyclic because the enablement relation is transitive; if A enables B, and B enables C, then A must transitively enable C, meaning C cannot enable A.

The representation of the ILO network followed in this thesis consists of directed pairwise relations between ILOs. In addition, there is presently one ILO-grouping pattern represented: the "definition triangle".

When ILO networks are compiled, certain motifs are identifiable. The “definition triangle” pattern recurred during the compilations of ILO networks investigated during the course of this research.

The definition triangle (DT) describes the association relationship between a name, a symbol and a definition. Association of this type is captured at the recall level of Bloom’s taxonomy (see section 2.2.3), and “name”, “symbol” and “definition” are examples of attributes from the attribute-value pairs of a concept (see section 2.2.4). Thus, the definition triangle applies to concepts at the recall level.

There are three elements, and therefore six unique pairwise relationships as shown in Figure 32. Each of the relationships is an ILO, and could be read as “Associate X to Y”, where X and Y are the elements in the relation.

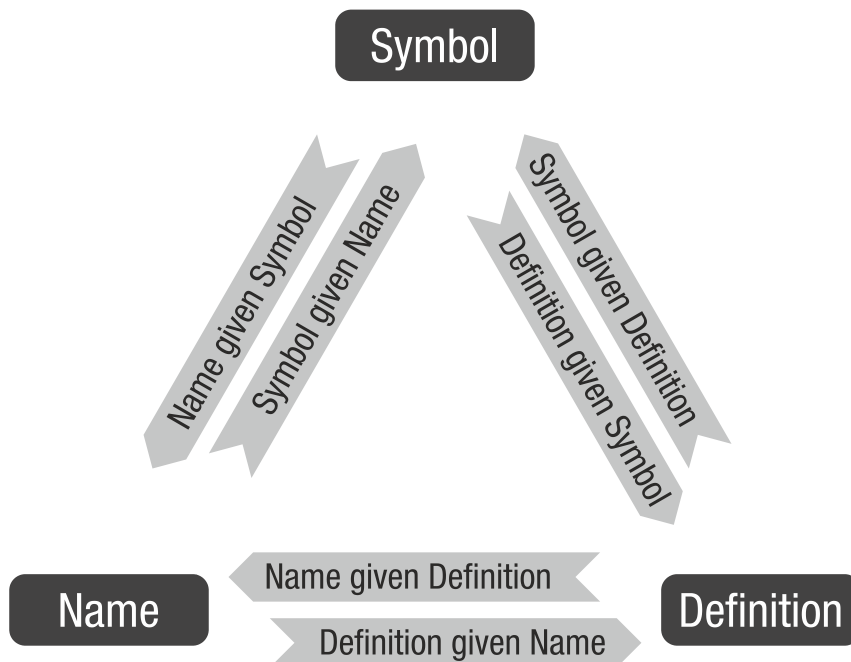


Figure 32 The definition triangle, showing three elements (name, symbol, definition) and the six pairwise associative relationships between them.

Figure 33 shows this relationship with an item of subject matter from music theory.

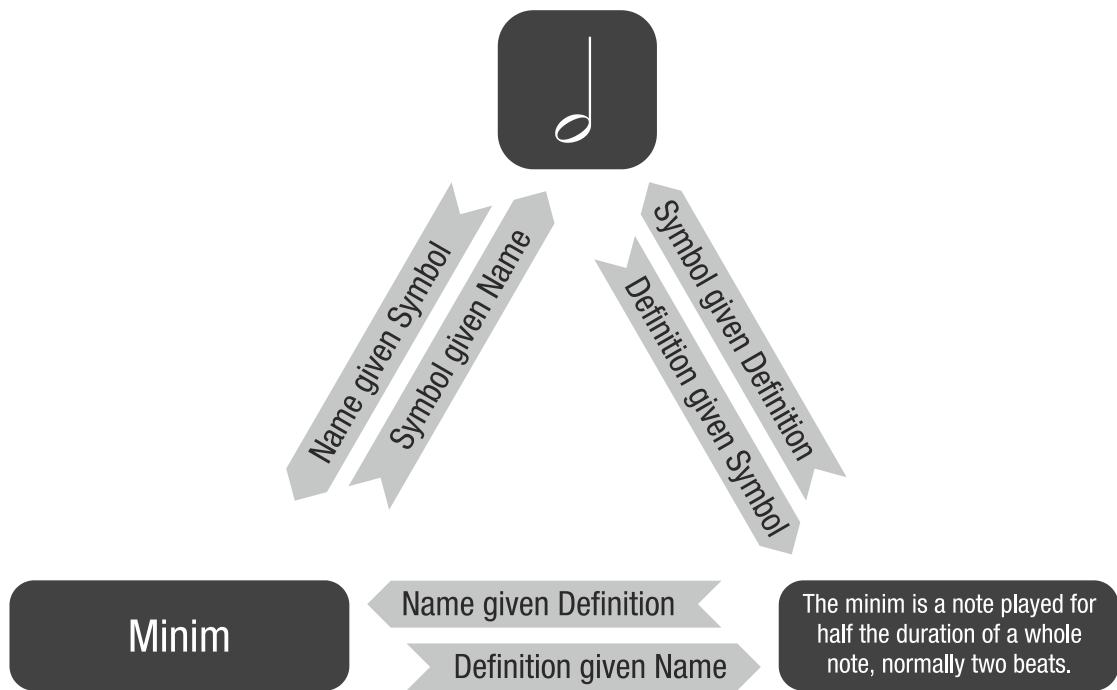


Figure 33 The definition triangle of "a minim" showing three elements (name, symbol, definition) and the six pairwise associative relationships between them.

In the ILO map evaluated in Chapters 0 and 0, a DT is represented as either:

- an undirected grouping of the six ILOs, or
- a single ILO where "Definition Triangle" (DT) takes the place of the capability, i.e. DT Minim.

These representations are synonymous. Experience showed that this level of granularity was unhelpful when examining and using the ILO network. Those examining the network during trials (see section 5.1.3) frequently grouped ILOs into definition triangles automatically and implied that the constituent ILOs could be pursued in any order.

The DT pattern is the only such pattern formally identified at present. Further development of ILO structures may reveal more.

3.2.3.3 Traversal Algorithms

Given a directed, acyclic ILO network, it is presumed that a user could navigate between two nodes. However, it is possible that there are differences in efficiency

between various traversal approaches. In addition, a learner approaching an ILO system may be unable or unwilling to route themselves. It is therefore sensible to model traversal (routing) algorithms for use with ILO networks. Foundational network traversal methods include breadth-first and depth-first approaches.

3.2.4 Risks

This section explores some risks associated with the use of ILO-informed systems.

3.2.4.1 Misuse of Tools

ILOs and ILO networks are models, and models are tools. Tools in themselves are passive and the only threat posed by the tool is the consequences of its misuse. Many of the criticisms of ILOs discussed in 2.2.6 address the misuse of ILOs as opposed to ILOs as a concept. An awareness of the limitations of ILOs, as well as their affordances, would constrain misuse of the tools.

These misuses might include teachers or learners inappropriately using an ILO-informed system to facilitate a “tick box” way of learning, surface learning, or artificially narrow learning. It is important to note however, that some topics are suited to such a style of learning. There is little desire to widely explore the topic areas of printer servicing or health and safety at work.

The use of ILO-informed systems could disenfranchise teachers if the teachers’ contributions were not valued. Auditing bodies could abuse the provision of ILOs, focussing on the measureable outcomes and neglecting to value the intangible outcomes achieved by students.

3.2.4.2 Intangible outcomes

The process of modelling educational goals into ILOs involves simplifying the complexities of subject matter, context, performance and capabilities to the format of ILOs. The process reduces the subject area into that which can be represented in ILOs. This “stripping” of learning can be considered unpalatable to domain enthusiasts, experts and teachers. It is important for all stakeholders to bear in mind that many topic areas involve nuances that cannot be easily defined; an ILO-informed system may be able to teach music theory, but it could not teach a musician how to

move an audience with a performance. Such intangible outcomes are not captured by ILOs, but they are important.

3.2.4.3 Technification

The use of ILOs and ILO networks could lead to “technification” in some quarters. Technification is a term discussed by Caeiro, Anido, & Llamas (2003) and describes the situation where technological education tools are only available to those teachers who have sufficient technical know-how to make use of them. They also identify issues caused by teachers building their course around technological tools, rather than the tools adapting to support the courses. Educators may feel obligated to make their courses “fit” ILO models, as opposed to revising the models themselves.

This also applies to learners lacking in technical skills, or those without equipment that would allow access to teaching software. ILO networks could be made hard-copy, but lose myriad affordances in the process, becoming nothing more than detailed curricula.

3.3 Summary

This chapter opened with a critique of the literature and ideas presented in Chapter 2. It showed sequencing as a teacher role, and showed that self-directed learners are ill equipped to sequence a progression through ILOs with which they are unfamiliar. The use of taxonomies offers ways of increasing the rigour and specificity of ILOs, but over reliance on these can lead to drawbacks, particularly if the wrong taxonomy is chosen for a given situation. KST is a potential alternative to ILO based systems, but issues around scalability and accessibility hamper its adoption. The chapter continued with a presentation of more detailed aspects of the system described in 1.2, incorporating the state of the art discussed earlier. Such systems incur risks, but most of these risks are associated with poor usage and over reliance on models.

The next chapter presents the research questions that have to be addressed in order to enable further development in ILO system research.

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4. Research Question and Methodology

This section presents the research question answered by this thesis, and the methodology used to collect the evidence that supports it.

4.1 Research Question

This thesis focusses on the use of routing algorithms to generate sequences of ILOs for learners. For the most part, teachers currently generate ILO sequences for learners. This thesis compares algorithmically generated sequences to those generated by teachers. This can be represented as a research question:

- 1) To what degree do routes of ILOs generated by algorithms differ from sequences of ILOs generated by teachers?

To inform this question, and to address the system described in the Motivations (Section 1.2), the following research sub-questions are addressed.

With regard to the models described in Sections 1.2 and 3.2.3:

- 2) Do non-subject matter experts understand and correctly interpret the specification and model for ILOs?
- 3) Do non-subject matter experts understand and correctly interpret the specification and model for ILO Networks?
- 4) Can non-subject matter experts relate the model to their own capabilities, that is, can they self-report their proficiency in a subject area in terms of ILOs?

Experiment 1, described in Section 4.2.1 addresses the sub-questions 2,3, and 4. Experiment 2, described in Section 4.2.2 addresses question 1.

4.2 Methodology

Two experiments were carried out. The first explored learner interpretations of ILOs and ILO networks. The second experiment involved teachers sequencing learning outcomes. These were then compared to the output of traversal algorithms.

An ILO network covering music theory was created from teaching resources available at www.musictheory.com. The process was similar to the noun-verb analysis detailed by Rosenberg & Stephens (2007) and informed by the work of Abbot (1983). The network was checked against the Associated Boards of the Royal Schools of Music's (ABRSM) music theory syllabus and differences were resolved or acknowledged.

4.2.1 *Experiment 1*

Experiment 1 consisted of four phases and investigated participant interpretation of ILOs and the network they formed.

Each participant undertook the experiment separately. During this experiment, the researcher sat next to each participant and observed their progress, taking notes from time to time.

4.2.1.1 Phase 1

The first phase of the experiment investigated how learners interpreted the formal representation of ILOs, and addresses research question 2: Do non-subject matter experts understand and correctly interpret the specification and model for ILOs?

Participants were shown an ILO written out in tabular format, along with an elaborated subject matter specification with fields taken from Merrill's CDT. They were then asked to select, from a list, a resource that most closely addressed that ILO. Phase 1 consisted of five of these ILO-Option items.

The resources were in the form of snippets of expository (telling or showing) or inquisitory (asking) resources. A sample question is shown in Figure 34 and the corresponding option sheet is shown in Figure 35.

Item 2

draw the sharp (#) symbol, given the name “sharp symbol”

More info

By the end of the lesson, the student will be able to draw the sharp (#) symbol, given the name “sharp symbol”.

Id	127
String	Draw 'Sharp' symbol
Level	Comprehension
Communication	Draw

Concept	id	c017
Prose	sharp	
name:	sharp	
is a	musical concept	
Where	definition	higher in pitch by a semitone
	effect	raises the pitch of the note the sharp is applied to by one semitone
	symbol	#

Figure 34 Sample ILO definition shown to participants

Options for Item 2

- a. "What does the sharp (#) symbol do?"
- b. The sharp symbol raises the pitch of a note by a semitone.
- c. A **flat sign** means "the note that is one half step lower than the natural note".
- d. Key signatures also can make all notes for sharps or flats consistent for the whole song.
- e.



Sharp Symbol	Natural Symbol	Flat Symbol
#		

Figure 35. Sample resource snippet sheet associated with the ILO definition shown in Figure 34. The expected match is option "e".

4.2.1.2 Phase 2

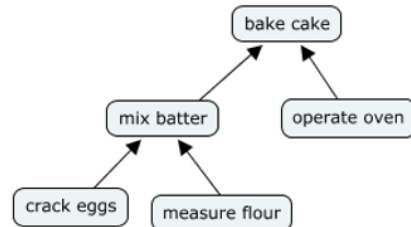
The second phase examines non-subject matter experts' understanding of the ILO network model, and addresses research question 4: Can non-subject matter experts relate the model to their own capabilities, that is, can they self-report their proficiency in a subject area in terms of ILOs?

It began with a brief introduction to the network, shown in Appendix I, and the relationships represented in it. The briefing is shown in Figure 36.

Section 2

The second section uses ILOs in an interconnected network.

This model is based on the idea of “probably necessary” connections.



In this example to the left, you probably need to be able to crack eggs and measure flour before you can mix batter. And you probably need to be able to mix batter and operate the oven before you can bake the cake.

This phase of this study tests how easily this kind of network can be interpreted, and gives some idea of missing links and nodes in the structure.

Examine the structure provided. Use colored pens to mark nodes, one colour for ILOs that you are reasonably confident that you could perform. Mark, in a different colour, ILOs that you definitely couldn't do.

Figure 36 Participant briefing for Phase 2 of experiment 1, here entitled "Section 2"

This phase involved participants inspecting the ILO network. Participants were asked to state their backgrounds in music theory and then to position themselves on the network by marking those outcomes they felt confident they could achieve if assessed, those they thought they were ready to learn, and those they knew nothing about and were not “ready to learn”. This experiment showed whether there was a correspondence between the learner background in music theory and their self-positioning on the ILO networks. This also indicated whether learners could interpret the ILOs in the context of a network.

4.2.1.3 Phase 3

The third phase introduction explained the concept of routing and the directional constraints of the arrows on the map, and addresses research question 3: Do non-subject matter experts understand and correctly interpret the specification and model for ILO Networks?

The Phase 3 briefing is shown in Figure 37.

Phase 3 asked participants to route between a given starting ILO and a given target ILO. Using the structure, the students enumerated a sequence of intermediate ILOs.

Research Question and Methodology

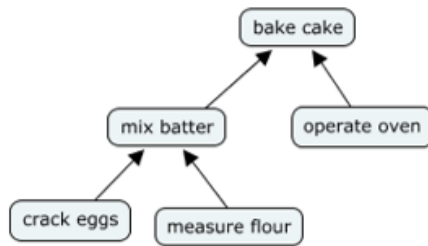
This tested their understanding of the network constraints and their abilities to use the structure for self-routing given their level of subject matter experience.

Section 3

The second section uses the same network of ILOs, and tests how “readable” the structure is.

With a well developed structure, it’s conceivable that a student could route themselves from basic knowledge, up to advanced concepts. It’s also conceivable that a computer could do the routing for them, and pass on appropriate resources for each ILO.

This section asks you to make “routes” through the network.



For example, using the cake structure. Sam wants to bake a cake, and can crack eggs.

A possible route would be:

crack eggs

measure flour

mix batter

operate oven

bake cake

An alternative would be:

crack eggs

operate oven

measure flour

mix batter

bake cake

But couldn't be

crack eggs

mix batter

operate oven

measure flour

bake cake

Your turn:

Given the same map from section 2, identify a sequence that will achieve the target node, given the starting node.

Starting node: “005, Define Staff”

Target node “042, Identify notes on the combined staff”

Starting node: “031, Define Compound time”

Target node “076, State note duration”

Starting node: “054, Define octave”

Target node “190, Recall semitones in Perfect fifth”

Figure 37 Briefing and tasks for Experiment 1 Phase 3

4.2.1.4 Phase 4

The fourth phase was an informal “comment and criticise” phase. Participants were invited to comment on the structure and the applications of it. This phase was not intended to produce data, but lead to comments and considerations to take forward into future work and experiments.

4.2.2 *Experiment 2*

Experiment 2 involved the participation of music teachers and focussed on comparing the routes of ILOs they generated with the routes generated by the traversal algorithms designed for the study. Experiment 2 addresses research question 1: To what degree do routes of ILOs generated by algorithms differ from sequences of ILOs generated by teachers?

4.2.2.1 Phase 1

Phase 1 consisted of a small number of interview questions that established how the teachers chose what music theory concepts to introduce, and in what order. This was conducted in a verbal, casual interview format, and teachers were invited to bring and share their relevant teaching resources. The questions asked were:

- How do you choose in which order to teach music theory topics to your students?
- What resources do you use to teach music theory?

4.2.2.2 Phase 2

In Phase 2, teachers were given a set of cards with ILOs written on them. One of the ILOs was marked as the target ILO. The teachers were asked to produce an ILO route that terminated at the target ILO.

This was repeated for a total of three sets of ILOs.

The ILOs in each set were sourced from different areas of the network in order to provide a mix of route lengths and a span of grade levels according to the ABRSM. The teachers were not shown the ILO network.

The target ILOs from each set are shown in Table 6.

Table 6 Target ILOs

Set	ILO Type
1	Build major scale i.e. write out C major
2	Name, write and explain the key signature of F Major
3	Build melodic minor scale e.g. Write out a melodic minor scale on manuscript paper

Each of the cards provided to the teachers represented an ILO from the network, that was necessary according to the network, to route to the target ILOs. In addition, some distractor ILOs were added (ILOs from the network that were not necessary for the route according to the network), and blank cards were made available if the teacher wished to add ILOs they thought were missing. Participants were invited to use and add as many cards as they thought appropriate. After the participants ordered the ILOs, the route was recorded in a photograph. An extract of one such photograph is shown below in Figure 38, showing five cards. The rightmost card is formatted with bold type, showing that it is a target ILO. Numbers written in the bottom corner of each card are identification numbers used by the researcher; participants were instructed to ignore them, and they did not reveal any “correct” sequencing. The fourth card in this sequence is a handwritten addition by the participant and reads “Write and play F major scale”.

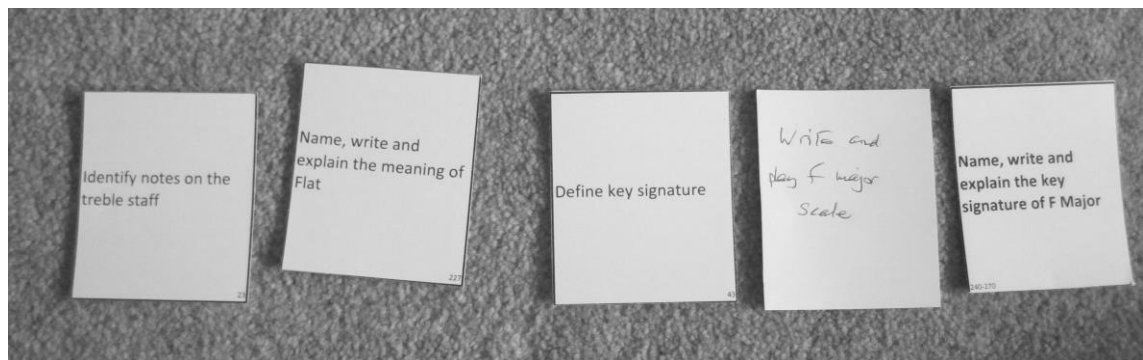


Figure 38 Extract of photographic recording of a route created by an Experiment 2 participant. Note the fourth card is handwritten by the participant and reads "Write and play F major scale".

The resulting teacher-authored routes were compared, in post-processing, to the routes produced by algorithms traversing the ILO network, shown in Appendix I, according to metrics of longest common substring length, longest common subsequence length, and edit distance.

4.2.2.2.1 Traversal Algorithms

Two algorithms were used, one breadth first (BF) type and one depth first (DF) type. As there is no left-right priority in the network, all possible permutations of traversal order were used.

The BF algorithm is a reversed level-order traversal (Berztiss, 1986). This approach visits leaf nodes first, exhausting a level before advancing to the next level. Figure 39 shows a sample network. The numbers in the nodes show the order in which they are visited. There are various permutations of order this algorithm could take.

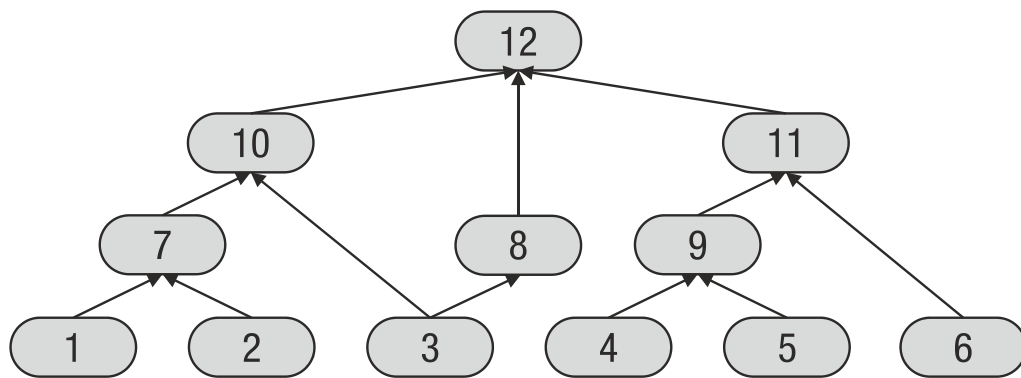


Figure 39 A permutation of the BF algorithm

The DF algorithm is a post order traversal (Xavier & Iyengar, 1998). This approach proceeds up levels until it encounters a node whose children have not yet been visited. Figure 40 shows a sample network traversed by the DF algorithm. The node number shows the order in which they are visited. Again, there are various permutations of order this algorithm could take.

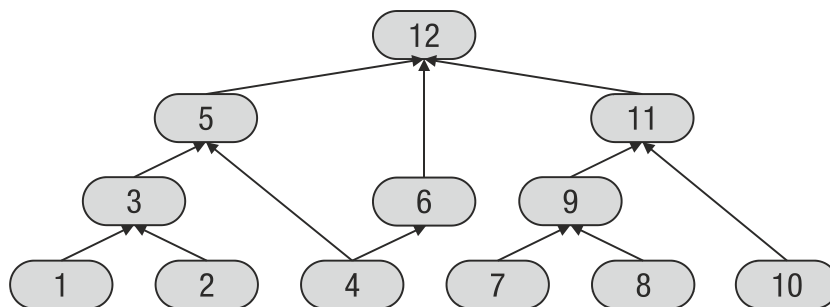


Figure 40 A permutation of the DF algorithm

The permutations evaluated were generated by Java code constructed for this project. The permutation generator included code from author Saurabh (2010)

4.2.2.2.2 Metrics

The routes generated by the teachers were compared to the routes generated by the algorithms by according to the metrics of longest common substring, longest common subsequence, and edit distance, techniques commonly used when comparing two digital files.

The longest common substring value is the length of the longest consecutive sequence of characters that occur in both strings. The longest common substring between of the words “perambulations” and “ambulance” is “ambula”, with a length of 6.

The longest common subsequence value is the length of the longest sequence of characters that occur in both strings, but not necessarily consecutively. The longest common subsequence of the words “happiness” and “paintballs” is “pins”, with a length of 4.

The edit distance of two strings is the number of insertion, deletions and substitutions that must be applied to one string in order to transform that string into the other. Each of these operations has a unit cost of 1. The edit distance between “more” and “dream” is 4.

Table 7 String transformation showing edit costs

String	Operation	Cost
MORE		
ORE	deletion of “M”	1
DRE	substitution “D” for “O”	1
DREA	insertion of “A”	1
DREAM	insertion of “M”	1

Table 7 shows how each operation of insertion, deletion and substitution is used. For this experiment, unit cost is applied to each operation, as there is presently no evidence to suggest any operation should have a higher cost.

These metrics are independent in that the value of one does not determine the value of another. However, they are interrelated. The length of longest common substring of two strings is the lower bound for the length of the longest common subsequence of those strings. The edit distance is bound by several characteristics: the upper bound is the length of the longer string, the lower bound is the length minus the longest common subsequence.

The strings generated by the teachers and the algorithms were evaluated in a Java string analysis class. The string analysis engine included code from Wikibooks.org (2014) (edit distance), Karich (2011) (longest common substring) and RosettaCode.org (2014) (longest common subsequence), and was verified with test cases.

4.3 Summary

This chapter introduced the research questions guiding this work, primarily around algorithmic routing, and secondarily concerning non-subject-matter expert interpretation of ILOs and ILO networks.

Experiment 1 addresses research questions 2,3, and 4, by testing participants' ability to interpret ILOs, to interpret an ILO network, and to position themselves on an ILO network.

Experiment 2 addresses research question 1, and compares the routes of ILOs generated by teachers to those generated by algorithms traversing the ILO network.

The next chapter presents the results of these experiments.

5. Results

This section details the results of the experiments described in 4.2. Raw data can be found in Appendices B, C, D and F.

5.1 Experiment 1

Experiment 1 consisted of four phases. The experiment briefing documents are available in Appendix A. Phase 1 asked participants to interpret ILOs. Phase 2 asked participants to interpret the ILO network in relation to their music theory experience. Phase 3 tasked participants with interpreting ILOs and the ILO network in order to create routes of ILOs that were possibly unfamiliar to them. Phase 4 invited the participant to comment qualitatively on the ILO network.

The experiment involved four participants from the researcher's peer group. The participants met with the researcher individually in an informal setting. Each phase followed the previous phase with no formal breaks. The participants were not compensated. The experiment was approved by the University of Southampton's Ethics Committee under reference number 6219.

5.1.1 Phase 1

The first phase of the experiment investigated how learners interpreted the formal presentation of the Intended Learning Outcomes. They matched ILOs to the resources they felt related best to the ILOs. Phase 1 took approximately 10 minutes to complete.

Participants were given five question items whose stems were ILOs, in prose and tabular form. Each of the five ILOs were associated with five options consisting resource snippets, presented as either diagrams, sentences or questions. Participants chose which resource snippet addressed the ILO by circling or otherwise marking the option on the option sheet. Some items had more than one correct option; provided the participant chose one correct option, the question was scored as correct.

A printing issue rendered several of participant 1's options incomplete, so their results were excluded from this analysis. Full data from the experiment is listed in Appendix B.

Results

Table 8 shows the probability of selecting a correct option by random choice, and the corresponding response performance by participants.

Table 8 Probability of answering an item correctly due to chance (left) and actual participant correctness (right). “1” represents a correct response, “0” represents an incorrect response.

Item Number	Number of Correct Options	p(correct by random selection)		Participant 2	Participant 3	Participant 4
1	2	0.4		0	1	1
2	1	0.2		1	1	1
3	3	0.6		1	1	1
4	1	0.2		1	0	1
5	1	0.2		1	0	1

A printing error failed to render special text in one of the options for item 5 for participant 2, but the error had negligible effect – the participant had experience in the area and correctly identified the missing data.

A Chi Square test indicates whether the participants’ performance was better than random chance selection, in selecting resources that applied to given ILOs.

Table 9 Expected and Observed frequencies of response types from Experiment 1 Phase 1 (Participants 2-4)

	Expected	Observed
Correct	4.8	12
Wrong	10.2	3

Table 9 includes expected frequencies of less than 5, so Yates’ correction for continuity is applied. The correction yields $\chi^2_{\text{Yates}}(1) = 14.43$, $p < .01$.

The result indicates that the participants were not guessing, and were instead correctly interpreting the ILOs and choosing appropriate resource snippets. This addresses research question 2: Do non-subject matter experts understand and correctly interpret the specification and model for ILOs?

5.1.2 Phase 2

The second phase involved showing participants the ILO network. Participants were asked to position themselves on the network by identifying the ILOs they felt they had achieved, and those that they were ready to learn according to their music theory experience. Participants took approximately 10 minutes to complete this phase. Representations for each of the participants can be found in Appendix C.

Participants were also asked to describe their music theory background. Based on their responses, the table of Experience Coefficients in Table 10 was compiled. The coefficient value is determined somewhat arbitrarily, but intends to quantify experience for the purposes of this experiment.

Table 10 Coefficients associated with experience level

Experience	Coefficient
No Experience	0.0
Primary School	0.2
ABRSM Grades 1-2	0.4
Secondary School	0.6
ABRSM Grades 3-4	0.8
Above ABRSM Grade 4	1.0

The participant results for Phase 2 are summarised in Table 11.

This shows each participant's self-declared experience level, the associated Experience Coefficient, along with the number of ILOs that the participants felt they had achieved, were ready to learn, and the ILOs that were subsequently left unmarked.

Results

Table 11 Music theory perceived capability and experience coefficients

Participant	Music Theory Experience	Experience Coefficient	ILOs Achieved	ILOs Ready to Learn	ILOs Unmarked
1	High School	0.6	13	27	42
2	Grade 8 ABRSM	1.0	69	13	0
3	Primary School	0.2	0	3	79
4	Primary School	0.2	0	5	77

The mapping of Experience Coefficient to ILOs marked as achieved is shown in Figure 41. The line of best fit shows, as intuitively expected, that for increasing experience, the number of ILOs achieved also increases.

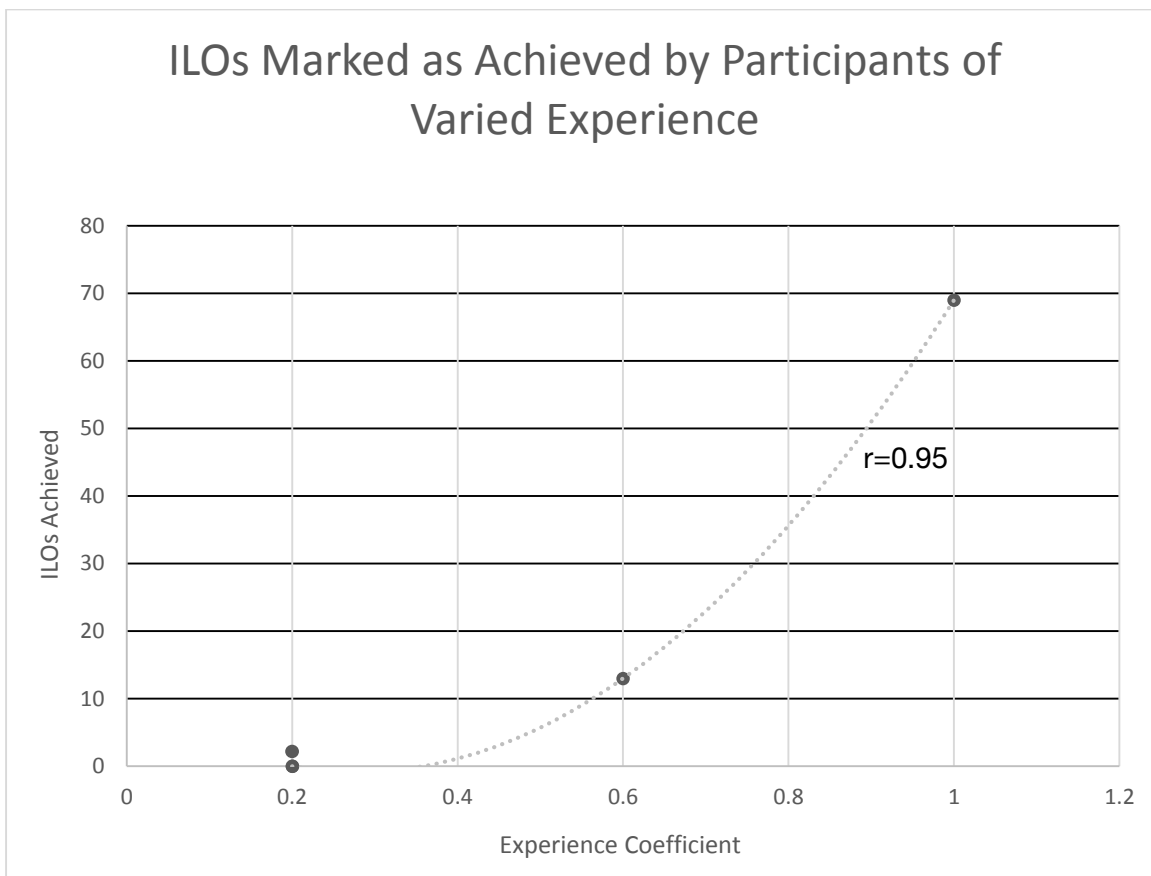


Figure 41 ILOs Marked as Achieved against Experience Coefficient. A data point has been added where two points overlapped at 0.2 on the Experience Coefficient axis.

A Pearson's product moment correlation coefficient shows the relationship between two variables. Here, the coefficient is calculated in order to show whether the self-declared experience of the participants is correlated with the number of ILOs they thought they have achieved. The result shows a positive correlation between the number of ILOs a participant marked as achieved and their experience coefficient, $r(2) = 0.947$, $p = .053$. This is very close to α and indicates that this result is highly suggestive.

This small participant sample does match common-sense assumptions that the more experience a participant has in a subject matter area, the more ILOs they feel that they have achieved. Research question 4 asks "Can non-subject matter experts relate the model to their own capabilities, that is, can they self-report their proficiency in a subject area in terms of ILOs?" These results suggest that learners can self-report accurately.

5.1.3 Phase 3

The third phase involved the same ILO maps as used in Phase 2. Participants were given a starting ILO and a target ILO and asked to describe a route of intermediate ILOs between the starting ILO and the target ILO. There were three such routes to create. Participants took approximately 20 minutes to complete this phase. These participant routes were compared to an exemplar route, derived from the ILO network. Table 12 shows the number of ILOs participants correctly included (CI), correctly excluded (CE), wrongfully included (WI) and wrongfully excluded (WE) according to the exemplar route. The number of ILOs in the "exemplar" route for each ILO start-target pair, is also shown.

Results

Table 12 Participant route qualities, where CI: correctly included, CE: correctly excluded; WI: wrongly included, WE wrongly excluded, and Exemplar CI: ILOs in route according to the ILO network.

		Route			
		1	2	3	
Participant	Exemplar Route	CI	11	17	16
		CE	100	94	95
		WI	0	0	0
		WE	0	0	0
	1	CI	11	17	16
		CE	98	94	72
		WI	2	0	23
		WE	0	0	0
	2	CI	11	17	3
		CE	100	94	93
		WI	0	0	2
		WE	0	0	13
	3	CI	9	9	3
		CE	98	94	72
		WI	2	0	23
		WE	2	8	13
	4	CI	11	9	2
		CE	98	94	93
		WI	2	0	2
		WE	0	8	14

The Correctly Included and Correctly Excluded values were summed into a correctly categorised value, for each participant over each route.

Table 13 Total correctly categorised values per route

		Route		
		1	2	3
Participant	1	109	111	88
	2	111	111	96
	3	107	103	75
	4	109	103	95

In order to determine whether the participants' routes were significantly different from the exemplar route, a Chi Square test on the correctly categorised totals for all of the participants over all of the routes, gave $\chi^2(12) = 22.14$, $p = .011$. This suggests that there was a difference between the routes generated by the learners, and the exemplar routes. In order to explore this further the correctly categorised scores were analysed on a per route basis, combining the participant scores. The Chi Squares for each route are shown in Table 14.

Table 14 Chi Square per route, for combined participant scores

	Routes		
	1	2	3
χ^2	0.216216	1.153153	20.77477
df	4	4	4
p	0.995	0.900	< .001

The results of the Chi Square tests suggest that only Route 3 routes created by the participants was different from the exemplar route. This would indicate that the participants were correctly interpreting the network for Routes 1 and 2, and not correctly interpreting the network for Route 3.

Route 3 shows significant difference, $p < .001$. This result is strikingly different to the others, and the data was interrogated to see if the difference could be explained. Investigation found that three of four participants wrongfully excluded from Route 3 the ILOs they had sequenced in Route 1, lowering their CI score.

These results suggest that the participants were able to correctly interpret the ILO network and route between two nodes. This experiment addresses research question 3: "Do non-subject matter experts understand and correctly interpret the specification and model for ILO Networks?"

5.1.4 Phase 4

Once the structured experiment was concluded, participants were informally invited to comment on the ILO network, ask questions, and hypothesise applications for ILO systems. These comments were opportunistic rather than part of the experiment, and not intended to produce data, but they led to interesting comments and considerations.

Results

Participant 1	The participant said of the network, “it’s like looking at how I think”. The participant suggested that students in the STEM domain are used to reading such logical structures, and that those studying Arts or Humanities may struggle.
Participant 2	<p>The participant asked for clarification on the prerequisite abilities for a student to be “at” a node – did that mean they can do all the things below that node?</p> <p>The subject asked about difficulty level, and target audience. It was not immediately clear from the overview sheet how the arrow relationships work.</p> <p>The subject asked what the researcher was looking for: what they thought would be best (as a relative subject matter expert) or what they thought other people would think best. The researcher advised the subject to imagine they were a teacher, and to represent the sequences that they would use to teach.</p> <p>This subject had extensive knowledge of music theory, and held an ABRSM Theory Grade 7 Music Theory qualification. The participant focussed far more on the subject matter relations captured in the network, and the exercise became one of verification of the network.</p> <p>In both this subject and the first, familiarity and apparent comfort came quickly after interacting with the network the first two or so times. Spontaneous grouping and exclusion behaviour occurred. At the end of the study, the participant expressed that if they were studying a subject unfamiliar to them, they would not pursue the minimum route. However, they did agree that they would wish to use the minimum route when challenged with a boring or utility subject matter area, e.g., printer servicing.</p>
Participant 3	The participant cautioned that the network may not be useful for non-stem subjects, but generally received the concept well.
Participant 4	The participant said they liked the layout as it made a new topic “less daunting”. They added: “It’s a useful way of seeing what you don’t know”.

5.2 Experiment 2

Experiment 2 involved ten participants who taught music professionally. The participants taught privately or within schools; some taught in both settings. The participants were known socially by the researcher. The participants met with the researcher individually in an informal setting. Each phase followed the previous phase with no formal breaks. The experiment was approved by the University of Southampton's Ethics Committee under reference number 7318. The experiment briefing documents are in Appendix E.

Experiment 2 consisted of two phases. Phase 1 asked participants to describe their sequencing strategies. Phase 2 asked participants to arrange ILOs in order to reach a target ILO.

5.2.1 Phase 1

Participants were asked about how they chose to sequence their student's exposure to music theory aspects.

Responses included:

- Teaching theory relevant to the piece of music they were studying.
- Using theory workbooks (all teachers in this study referred to ABRSM and some additionally referred to schemes of work in school settings). Workbooks were commonly used by teachers intending to guide their pupils through the ABRSM grades.
- One participant mentioned "age appropriateness" but did not elaborate further.

This phase was necessary in order to ascertain if the teachers were sequencing their content according to an external influence (a curriculum etc.), whether they had an "internal map", or whether they were routing reactively, adapting to their learners and context.

The teachers generally indicated that they acknowledged some external guidance, notably from the ABRSM curriculum, but were mainly influenced by the music pieces their students' were learning, and student curiosity and receptiveness.

5.2.2 Phase 2

Participants were given a set of cards with ILOs written on them (one target ILO, the rest intermediate ILOs) and asked to arrange the ILO cards in the order in which they would teach their students, thus generating routes. The was repeated three times, for a total of three sets of ILOs. The participants were not shown the ILO network.

The routes generated by each participant were compared to those generated by the BF and DF algorithms traversing the network, and to the routes generated by the other participants on the metrics of longest common substring (LC Sst), longest common subsequence (LC Ssq), and edit distance (ED).

The resulting values were normalised to a uniform route length arithmetically. The differences between each of the approaches and each teacher for each metric were calculated. These values were averaged, yielding “scores” for each metric for the BF algorithms, the DF algorithms and the Teachers (T). Performing a multivariate analysis on these scores was not possible as there were insufficient residual degrees of freedom. Instead, three univariate analysis of variances operations were performed.

These show, for each metric, if the routes generated by routing algorithms vary from those produced by teachers more than teachers vary between themselves. This will indicate whether algorithms can route similarly to teachers, addressing the main research question in this thesis.

5.2.2.1 Results of Longest Common Substring Scores

Table 15 shows descriptive statistics for LC Sst scores along with standard error of the mean. It can be seen that the mean LC Sst scores for Set 3 are all lower than those for Set 1 and Set 2.

Table 15 Descriptive Statistics for LC Sst Scores, for each Set (set of ILOs) and each approach, where standard (Std.) error is given by (standard deviation)/ $\sqrt{(\text{sample size})}$

Set	Approach	Mean	Std. Error
1	BF	167.4	16.1
	DF	175.2	20.0
	T	157.4	11.0
2	BF	154.0	12.2
	DF	179.7	15.4
	T	183.8	23.2
3	BF	102.4	9.1
	DF	127.4	18.3
	T	103.3	7.5

These values are graphed in Figure 42. Within each Set, the error bars overlap. Between Sets, Set 3 has lower LC Sst scores than both Set 1 and Set 2.

Results

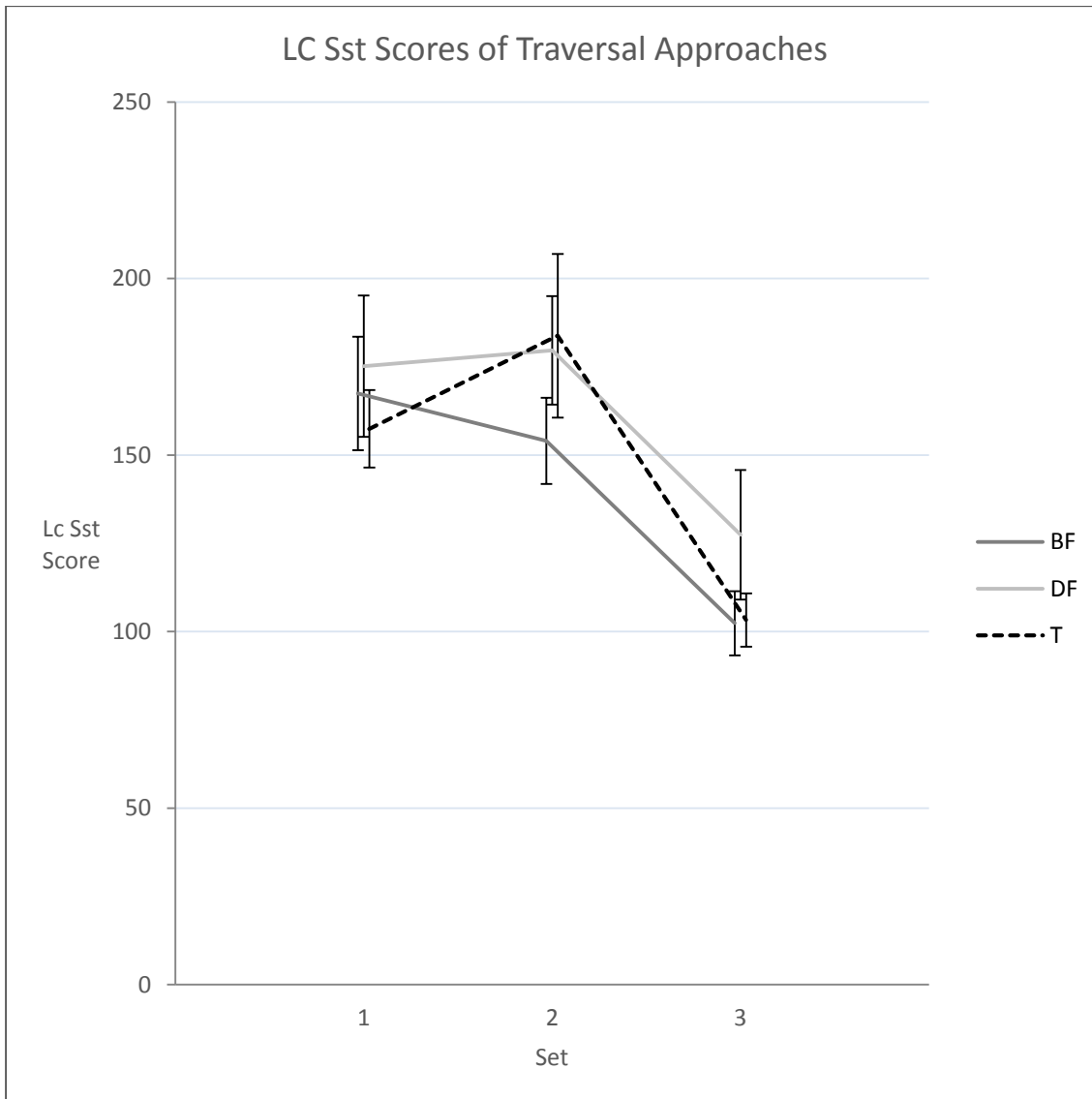


Figure 42 Mean LC Sst score by Approach for each Set. The data points have been offset by a small amount to more clearly show the error bars representing standard error.

A repeated measures two-way analysis of variance (ANOVA) was carried out using SPSS. Table 16 shows the summary table for the effects of Set and Approach on LC Sst score.

Table 16 ANOVA summary table of Set and Approach for LC Sst score

Effect	F	Hypothesis df	Error df	Sig.
Set	18.150	2	8	.001
Approach	1.694	2	8	.243
Set * Approach	.864	4	6	.536

The interaction effect of Set * Approach is not significant ($p = .536$), suggesting that the main effect of Set and Approach can be directly interpreted. Figure 42 illustrates this insignificant interaction.

The effect of Approach is not significant ($p = .243$), suggesting that, over all sets, the mean LC Sst score of the three approaches are not significantly different. This implies that, for the metric of LC Sst score, BF and DF algorithm routes do not vary from teachers' routes more than teachers vary amongst themselves.

The main effect of Set is significant ($p = .001$), indicating that some property of the set of ILOs has a significant impact on the LC Sst scores. This effect of Set on LC Sst score is graphed in Figure 43.

Results

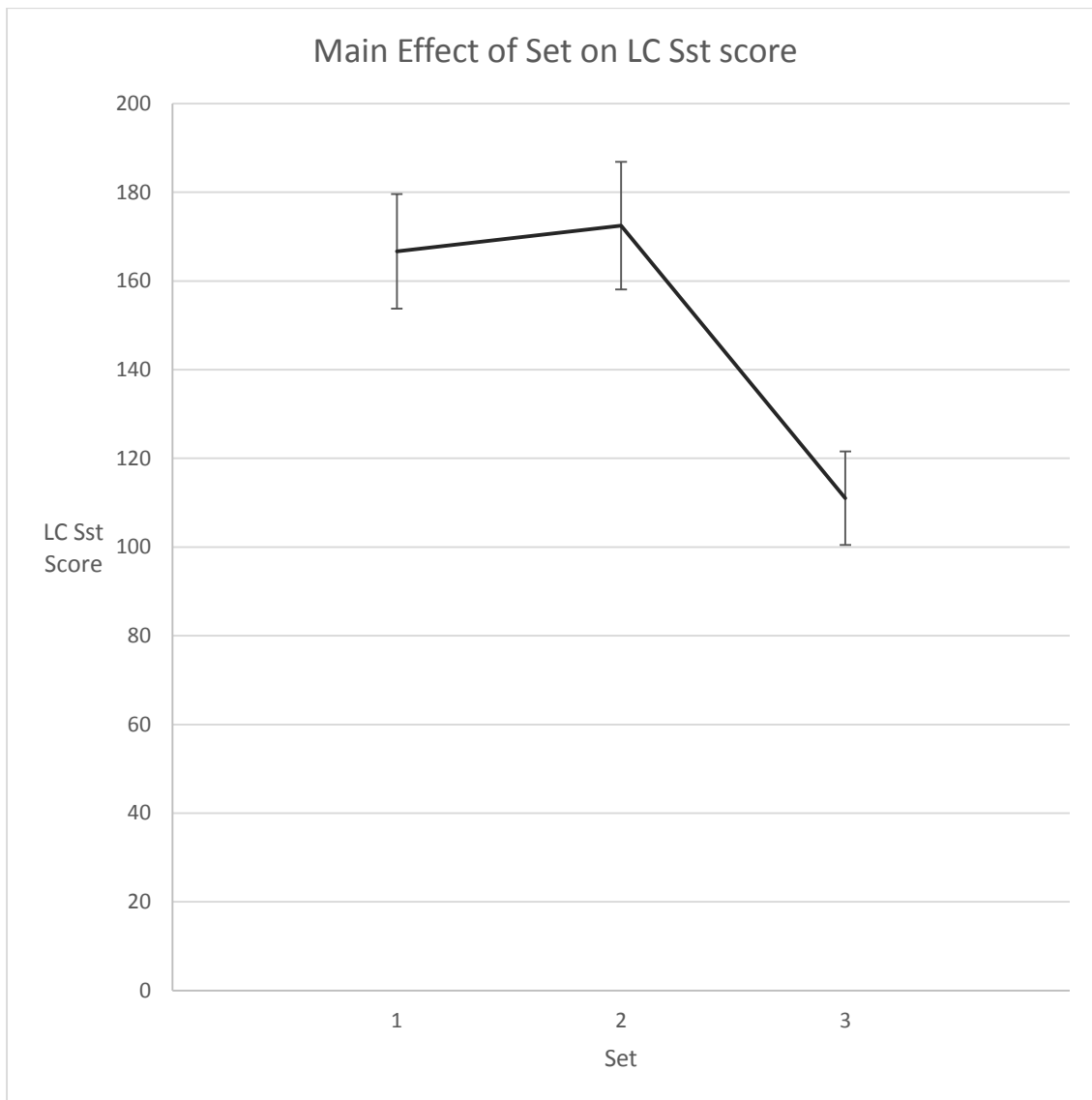


Figure 43 Main Effect of Set on LC Sst Scores. Error bars show standard error of means.

The profile line in Figure 43 shows that routes algorithmically generated for Set 3 had significantly shorter substrings in common with teachers (non-overlapping error bar). Because Set 3 contained more ILOs than either of the other sets, an increased number of route permutations may have resulted in a lower average LC Sst score.

5.2.2.2 Results of Longest Common Subsequence Scores

Table 17 shows descriptive statistics for LC Ssq scores along with standard error of the mean. It can be seen that the Scores for Set 3 are all lower than those for Set 1 and Set 2.

Table 17 Descriptive Statistics for LC Ssq Score, for each Set and each approach, where standard (Std.) error is given by $(\text{standard deviation})/\sqrt{(\text{sample size})}$

Set	Approach	Mean	Std. Error
1	BF	351.0	21.0
	DF	336.9	25.5
	T	308.0	12.1
2	BF	343.2	28.4
	DF	370.3	29.8
	T	342.2	23.5
3	BF	283.0	26.4
	DF	285.6	34.0
	T	253.9	17.0

These values are graphed in Figure 44. Within each set, there is noticeable overlap of error bars. Between Sets, Set 3 has lower LS Ssq scores than both Set 1 and Set 2.

Results

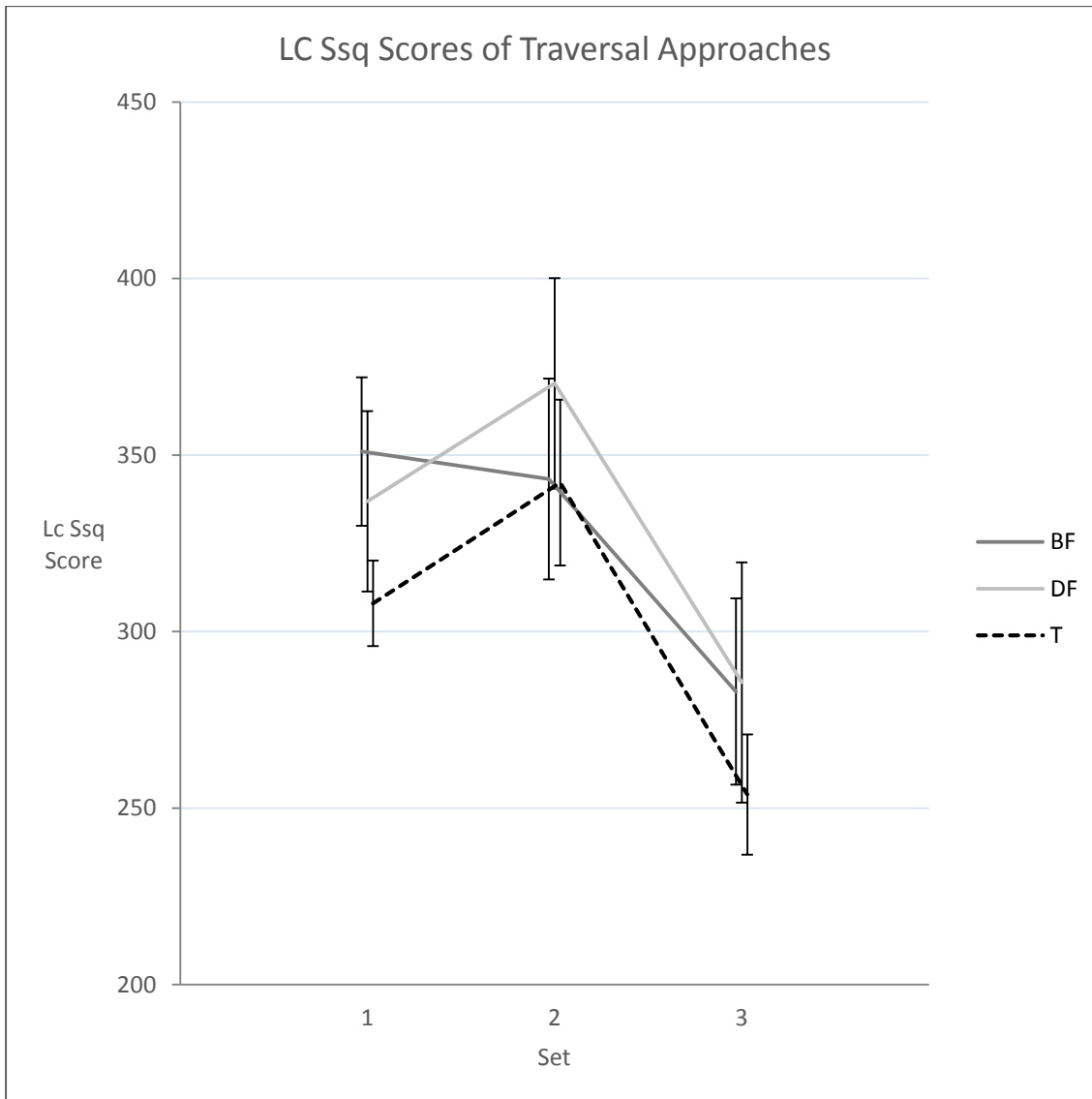


Figure 44 Mean LC Ssq score by Approach for each Set. The data points have been offset by a small amount to more clearly show the error bars representing standard error.

A repeated measures two-way analysis of variance was carried out using SPSS. Table 18 shows the summary table for the effects of Set and Approach on LC Ssq score.

Table 18 ANOVA summary table of Set and Approach for LC Ssq score

Effect	F	Hypothesis df	Error df	Sig.
Set	6.229	2	8	.023
Approach	6.378	2	8	.022
Set * Approach	3.332	4	6	.092

The Set * Approach interaction is not significant ($p = .92$), suggesting that the main effect of Set and Approach can be directly interpreted. Figure 44 illustrates this insignificant interaction.

The effect of Set is significant ($p = .023$) indicating that some property of the set of ILOs has a significant impact on the LC Ssq scores. The effect of Set on LC Ssq score is graphed in Figure 45.

The effect of Approach is significant ($p = .022$) indicating that some property of Approach has a significant impact on the LC Ssq scores. The effect of Approach is graphed in Figure 46.

Results

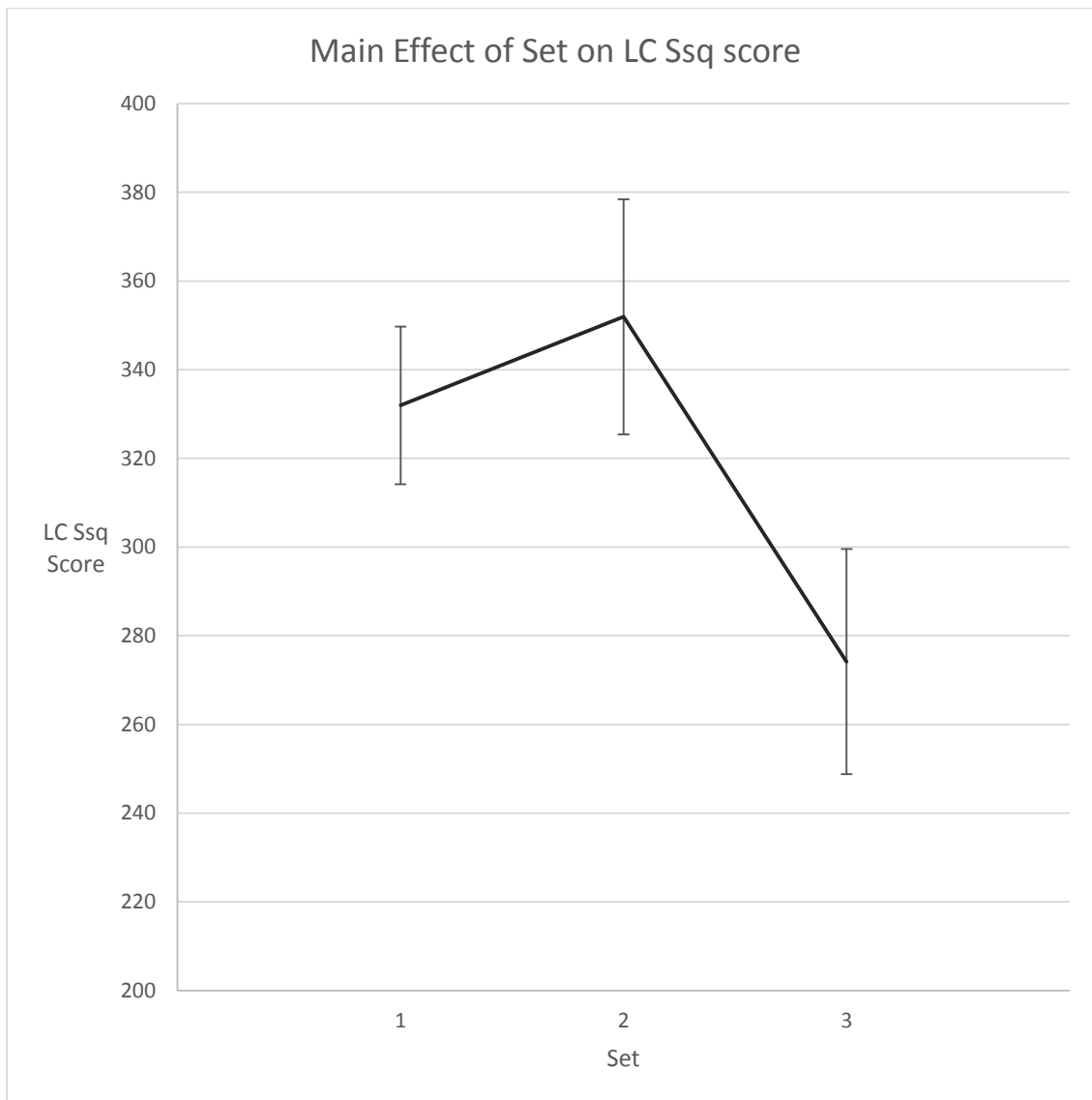


Figure 45 Main Effect of Set on LC Ssq score. Error bars show standard error of means.

The profile line in Figure 45 shows that routes generated for Set 3 had significantly shorter subsequences in common with teachers (non-overlapping error bars), regardless of the approach taken to generate the routes. A similar characteristic for Set 3 was also seen in the substring metric, discussed in section 5.2.2.1. Because Set 3 contained more ILOs than either of the other sets, an increased number of route permutations may have resulted in a lower average LC Ssq score.

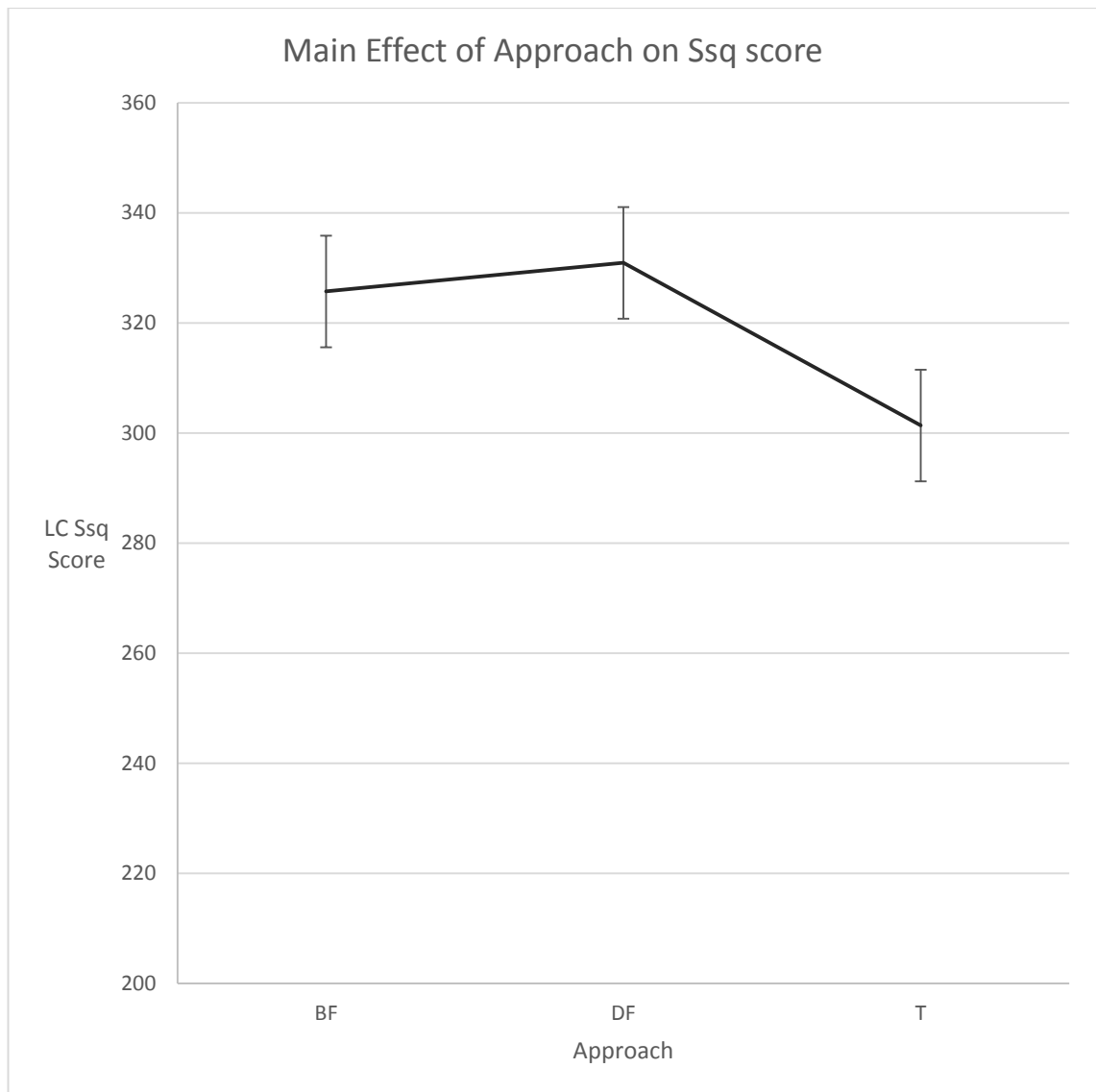


Figure 46 Main Effect of Approach on LC Ssq score. Error bars show standard error of means.

The profile line in Figure 46 shows that Teachers had greater variance amongst themselves than they did with either of the algorithmic approaches (a lower score with non-overlapping error bar). This may be an effect of teachers inserting custom ILOs.

Results

5.2.2.3 Results of Edit Distance Scores

Table 19 shows descriptive statistics for Ed scores along with standard error of the mean.

Table 19 Descriptive Statistics for Ed for each Set and each approach, where standard (Std.) error is given by (standard deviation)/ $\sqrt{(\text{sample size})}$

Set	Approach	Mean	Std. Error
1	BF	333.0	25.7
	DF	344.6	31.9
	T	292.6	16.0
2	BF	413.6	23.6
	DF	389.4	27.2
	T	412.6	17.4
3	BF	422.9	15.9
	DF	403.7	19.5
	T	357.2	12.2

These values are graphed in Figure 47.

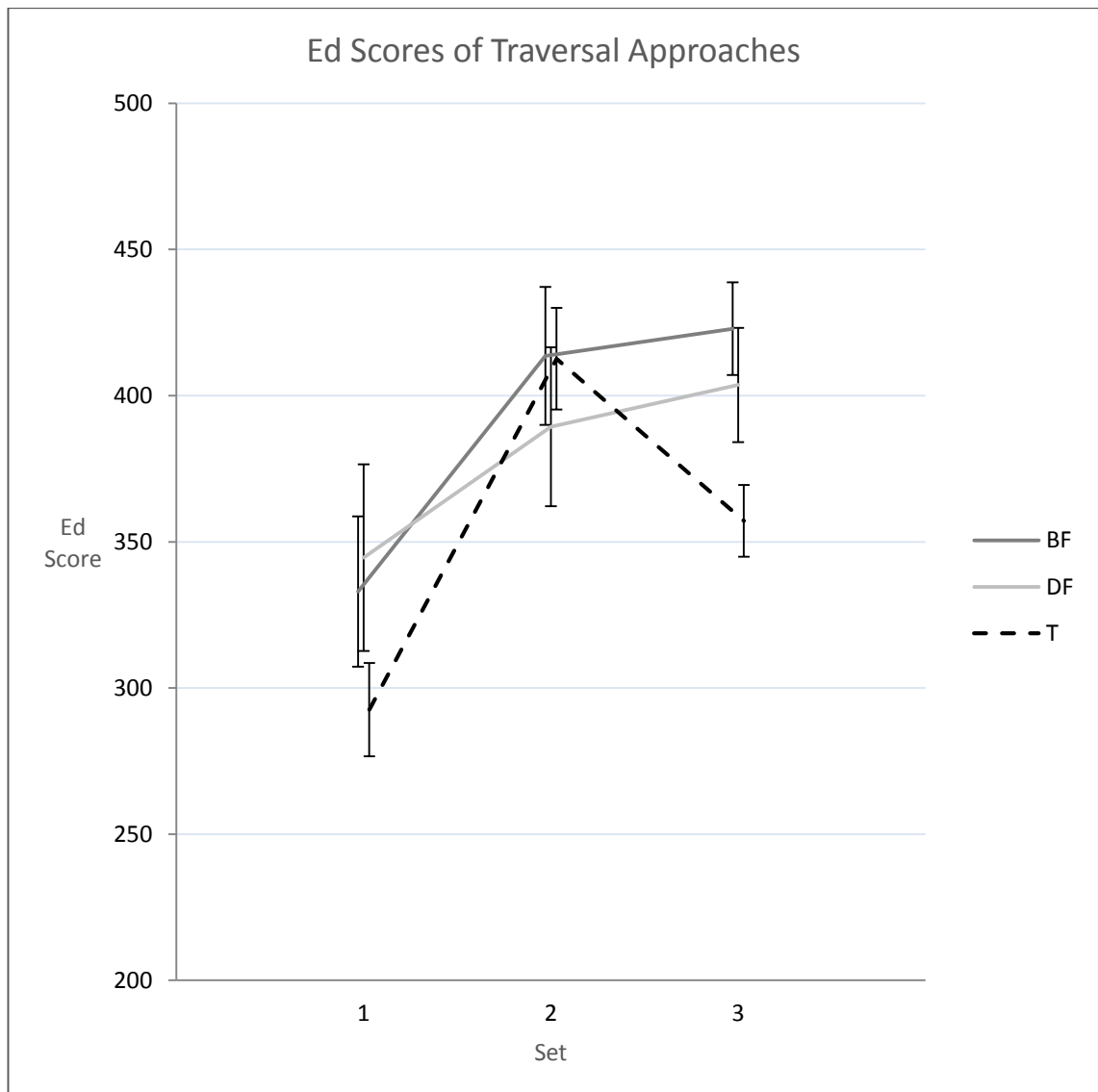


Figure 47 Mean edit distance score by Approach for each Set. The data points have been offset by a small amount to more clearly show the error bars representing standard error.

A repeated measures two-way analysis of variance was carried out using SPSS.

Table 20 shows the summary table for the effects of Set and Approach on Ed score.

Table 20 ANOVA summary table of Set and Approach for Ed score

Effect	F	Hypothesis df	Error df	Sig.
Set	6.771	2	8	.019
Approach	37.594	2	8	.000
Set * Approach	1.894	4	6	.231

Results

The Set * Approach interaction is not significant ($p = .231$), suggesting that the main effects of Set and Approach can be directly interpreted.

The effects of Set are significant. This suggests that over all Approaches, there are differences in mean Ed scores between the three Sets. The effect of Set on Ed score is graphed in Figure 48.

The effects of Approach are significant. This suggests that over all Sets, there are differences in mean Ed scores between the approaches. The effect of approach on Ed score is graphed in Figure 49.

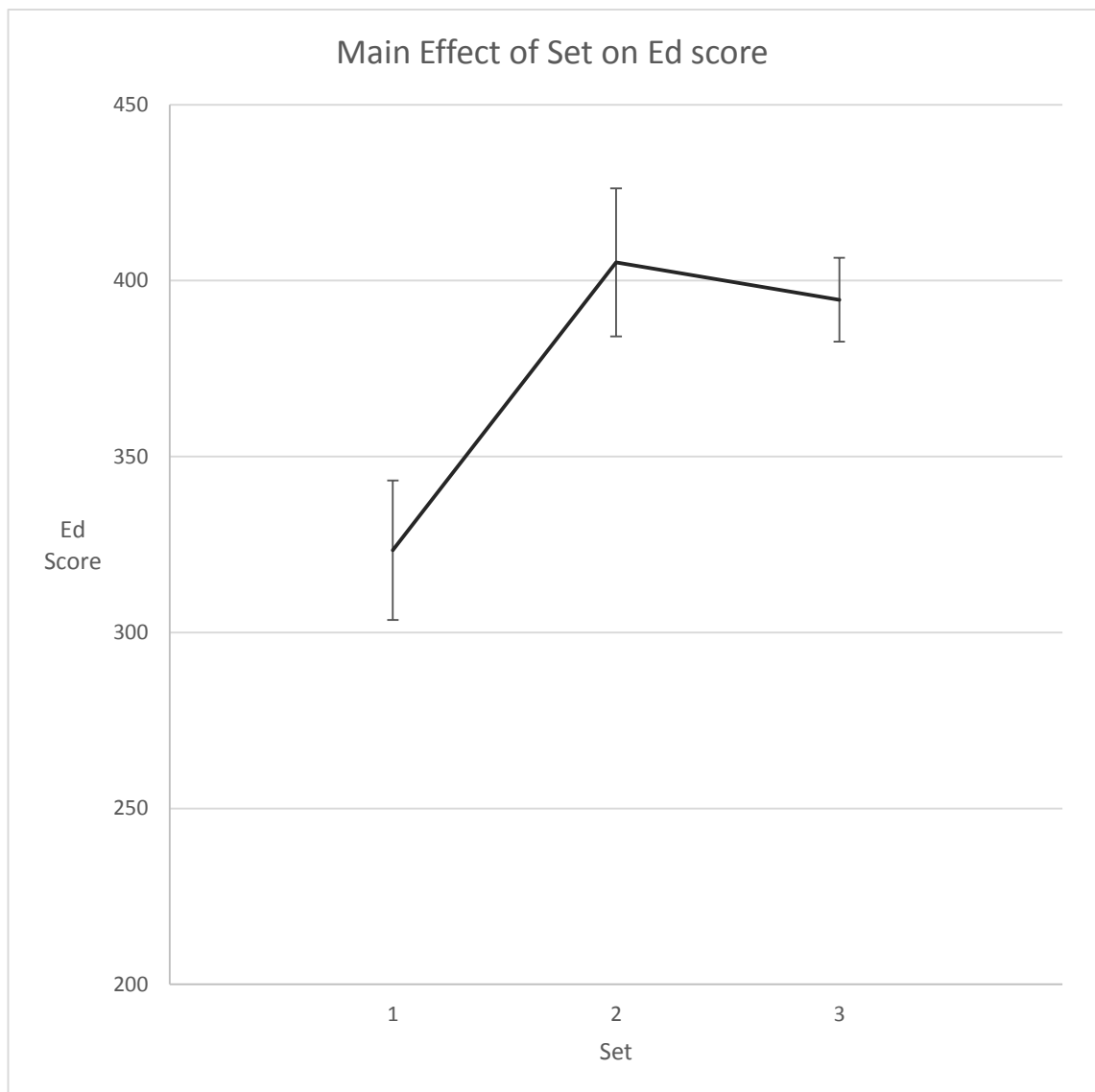


Figure 48 Main Effect of Set on Ed score. Error bars show standard error of means

The profile line in Figure 48 shows that Edit Distances scores for routes generated for Set 1 were significantly lower than the other routes (a lower Ed score, with non-overlapping error bar). This may be because Set 1 was a smaller, introductory set, and there were fewer permutations for ordering than in the other sets.

Results

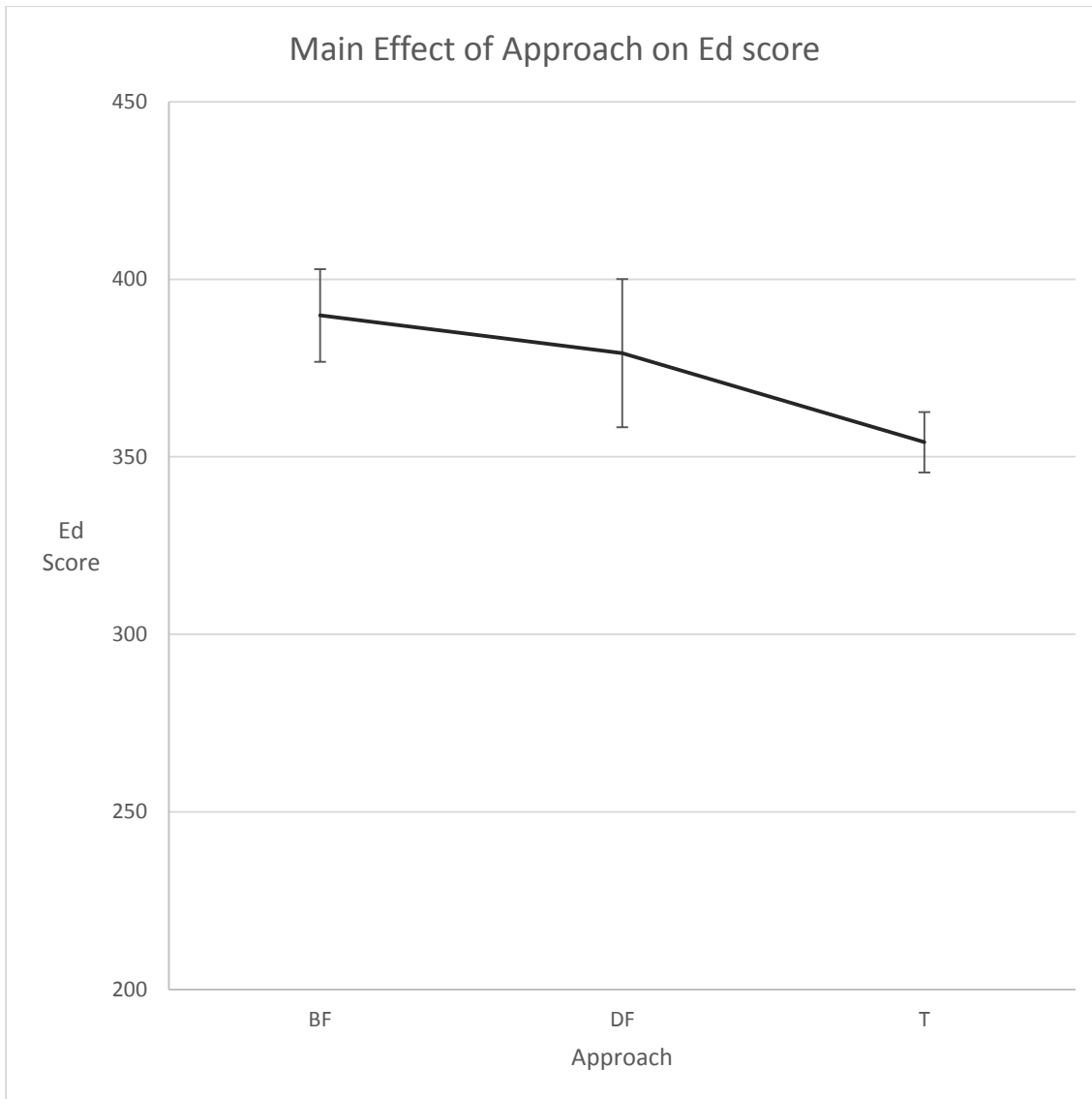


Figure 49 Main Effect of Approach on Ed score. Error bars show standard error of means.

The profile line in Figure 49 shows that the Edit Distance scores between teachers and their peers were significantly lower than the Edit Distance scores between teachers and the BF approach (non-overlapping error bars). This may be an effect of the difference in route lengths. The algorithms had fixed length routes governed by the ILO network, compared with the flexible lengths that the teachers could generate. This is further discussed in 6.2.2.3.

5.3 Summary

This chapter presented the results gathered from the experiments described in Chapter 4.

Experiment 1 focused on non-subject-matter experts and examined their abilities to interpret ILOs and ILO networks, to interpret an ILO network and create routes, and their ability to position themselves within an ILO network..

Experiment 2 focused on the differences and similarities between algorithmically generated routes of ILOs, and teacher generated routes of those same ILOs. Results indicated that, for the most part, the algorithmically generated routes differed from teachers no more than teachers differed from each other.

The next chapter discusses these results in more detail, and explores the implications of the results

Results

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6. Discussion of Results

This chapter discusses the results shown in Chapter 5.

6.1 Experiment 1

Experiment 1 involved four participants and consisted of four phases. This experiment was a pilot study and explored non-subject matter expert interactions with ILOs and the ILO network.

6.1.1 Phase 1

Experiment 1 Phase 1 asked participants to match an ILO description to resource snippets they thought best addressed the ILO. This experiment offers evidence to the claim that non-subject matter experts can interpret ILOs.

6.1.1.1 Discussion of Phase 1

The participant scores were compared with scores generated by random selection, in a Chi Square test.

The Chi Square $\chi^2(1) = 15.88$, gives $p < .01$. With Yate's correction applied, the result is $\chi^2_{\text{Yates}}(1) = 14.43$, $p < .01$.

The Chi Square suggested that the participant scores were independent from scores generated by chance, indicating that the participants were not guessing and were therefore correctly interpreting the ILOs.

One participant paid noticeable attention to the subject matter tables when completing Phase 1. When this was queried after the study, the participant said they had paid little attention to the ILO phrase or table, and had focussed on the subject matter table to inform their selection of resource snippet.

A second participant also seemed to be interpreting the content in the subject matter table rather than the ILO, and using the ILO phrase only to verify the selection they had made based on the subject matter.

These results suggest that non-subject matter experts can interpret ILOs, and that elaboration of the subject matter of the ILO is helpful to do so.

6.1.1.2 Limitations of Experiment 1 Phase 1

Experiment 1 ran with a small sample. Phase 1 was further limited because the results from Participant 1 were uncoded due to several of the options on the option sheet not printing correctly. The participants were all graduates or undergraduates, from similar socio-economic backgrounds. The inclusion of more participants with more diverse backgrounds would have more comprehensively reflected the capabilities of non-subject matter experts.

Phase 1 consisted of five questions. More questions may have more accurately reflected participants' interpretation of ILOs.

The items and options were constructed by the researcher, who has had no formal training in the construction of multiple choice questions. Verification of suitability from an expert in the construction of multiple choice questions may have improved the test quality.

Subjects were not pretested to determine their music theory competence. As such, it is not possible to be certain that they did not know the subject matter in advance of the experiment. Their status as non-subject matter experts was not validated.

6.1.2 Phase 2

Experiment 1 Phase 2 asked learners to state their prior music theory experience and to position themselves on the network by categorising ILOs into one of three groups:

- ILOs they felt they could achieve,
- ILOs that they thought they were ready to learn,
- and ILOs that they were not ready to learn.

6.1.2.1 Discussion of Phase 2

The results of Phase 2 suggest that the more experience a participant has in music theory, the more ILOs they felt they had achieved. This is an expected relationship, and should hold for other subject areas.

Several participants positioned themselves contrary to the network's constraints – that is, they labelled some ILOs as achieved whilst marking the enabling ILOs for those

ILOs as not yet achieved. This is clearly shown in the bottom-right portion of Participant 2's positioning network shown in Appendix C). This means that either the network or the participants were in error. Upon investigation, the network was flawed in that it lacked resolution in grouping in that area.

The DT, as introduced in 3.2.3.2 and shown in Figure 32, showed its significance. Participants seemingly could not distinguish between the components of a DT and treated them as a single entity.

6.1.2.2 Limitations of Phase 2

Phase 2 assumed that participants were able to correctly interpret ILOs. The results of Phase 1 suggest that participants can interpret ILOs, but that subject matter elaboration is relied upon. The network shown to participants in Phase 2 did not have any elaboration of subject matter. Some participants asked for clarification of the meaning of some ILOs. It is possible that participants did not understand the ILOs they were positioning themselves with. It was also assumed that the network was complete and correct.

6.1.3 Phase 3

Experiment 1 Phase 3 asked participants to create a route between a given starting ILO and a given ending ILO.

6.1.3.1 Discussion of Phase 3

Phase 3 was designed to test whether non-subject matter experts were able to route between two ILOs successfully. The results showed no significant difference between the participants' routes and the exemplar route, except in the case of Route 3

Participant routes for Route 3 were less similar to the exemplar compared to the other two routes. Investigations into the actual participant routes shows that three of the participants failed to include ILOs that formed Route 1. The participant that did include Route 1 did so seemingly offhandedly, grouping the ILOs as one unit that had already been routed through. It is possible that the other participants mentally marked that sub network as included or already learned.

In general, where ILOs were left out, participants overlooked necessary ILOs that were geometrically below or to the left of the starting ILOs on the network. Where extraneous ILOs were included, they tended to be geometrically 'logical'; that is, they

were arranged on the network that visually suggested that they belonged with their neighbouring nodes. This was confirmed by a participant when queried after the experiment. Spatial layout of the ILO network representation may affect learner interpretation of ILO networks.

Most participants grouped DT ILOs (section 3.2.3.2) as single units and therefore included all six ILOs of the triangle into their routes indiscriminately. When this was queried, a participant suggested the distinctions were trivial and not worth separating. Another participant stated that they believed the additional effort of achieving the superfluous ILOs in the group was negligible. This is an example of marginal utility of specification. Participants seemed to have a common interpretation of “Name, Define and Represent X”.

One participant included groups as if the group was a single ILO, but then ordered within the group. That is, they made sub-routes. The participant also grouped nodes that were not geometrically close to each other, but that had the same form, i.e. “identify notes on the bass staff” and “identify notes on the treble staff”. The participant indicated that these could be done in any order.

These grouping behaviours did result in unnecessary ILOs being included in the paths. The grouping behaviours led to revisions of the network for Experiment 2, most notably the representation of DTs (see section 3.2.3.2).

6.1.3.2 Limitations of Phase 3

The instructions given for Phase 3 were insufficiently specific. One participant was unsure of whether the route was meant to be “what they would teach” as opposed to “what the diagram says”. The researcher instructed the participant to do what they thought was appropriate. It is possible that the other participants were working under conflicting assumptions.

6.1.4 Phase 4

Experiment 1 Phase 4 asked participants for their comments on the network. This phase was unstructured and informal.

The reception of the network was mostly positive. However, as participants were drawn from the researchers peer group, biases were likely in effect. Uniformly and

unprompted, the participants expressed some reservation as to whether the network would be applicable or useful in non-STEM subjects. Participants seemed to value the overview offered by the network, potently expressed by Participant 4 stating “It’s a useful way of seeing what you don’t know”.

6.1.5 Other observations

The researcher observed that the participants’ use of, and trust in, the network appeared to vary for all participants throughout their sessions. When they were confident in the subject matter, they tended to use that knowledge to route through the network. When they were not, there was no apparent reluctance to use the structure and route accordingly.

When interpreting ILOs, participants uniformly engaged in reading the information-dense subject matter table, rather than the ILO. Different results may have been gathered if the ILO have been presented alone.

Participants engaged in a number of problem solving techniques – interpretation of the ILO sentence, the subject matter table, and the arrow layout. Best results seemed to be achieved when it appeared all three were used simultaneously.

All participants got better at interpreting and routing with experience. A small session of training prior to the study may have resulted in them performing more consistently.

6.2 Experiment 2

Experiment 2 involved ten participants and consisted of two phases. This experiment involved subject matter experts who were music teachers. They performed the experiment without first seeing the ILO network, though it was shown to them after the experiment.

6.2.1 Phase 1

Phase 1 asked participants to describe qualitatively how they chose what aspects of music theory to teach their students, and when to introduce them.

All teachers in the study referred to the ABRSM, and many used workbooks produced by the Association. Those taking students through grades chose pieces of music specified by the Associations syllabus. These results indicate that the music theory ILOs, at the level of expertise described here, are predominantly common to the teachers in the sample. Any outlying ILOs are likely to be specific to an instrument or a piece of music.

6.2.2 Phase 2

Phase 2 asked participants to order ILOs in the order in which they would teach their students. Each teacher's route was compared to route generated by algorithms (referred to as BF and DF), and to those generated by the other teachers (referred to as T). The routes were encoded as strings of letters and compared according to the metrics of longest common substring length (LC Sst), longest common subsequence length (LC Ssq), and edit distance (Ed) (see section 4.2.2.2.2). These results were normalised and consolidated in order to allow a comparison between the approaches for each route. A repeated measures ANOVA was performed for each of the metrics.

6.2.2.1 Discussion of SubString Scores

Figure 42 shows the values of mean LC Sst scores by Approach, illustrating the results found in the accompanying Table 15. Table 16 shows an ANOVA summary table for Sst scores, and indicates no significant difference between Sst scores according to Approach, or the interaction of Approach and Set. This is suggested by the areas of error bar overlap in Figure 42. This suggests that the routes of both algorithms had similar lengths of substring in common with the teacher-produced

routes as the teacher-produced routes did with each other. This indicates that algorithms can route similarly to teachers in terms of producing identical substrings (sub-routes).

The ANOVA results show significance for Set, and the main effect of Set is illustrated in Figure 43. This figure shows that routes generated for Set 3 had shorter substrings in common with teachers, regardless of the approach taken to generate the routes. Set 3 was the longest of the Sets, and this variation could be a result of increased permutations of the ILOs available.

6.2.2.2 Discussion of Subsequence Scores

Figure 44 illustrates the descriptive statistics of the mean LC Ssq scores by Approach found in Table 17. The ANOVA summary, shown in Table 18, shows no significant effect of the interaction between Set and Approach. This is indicated by overlap in error bars in Figure 44, suggesting that there is no significant difference between the teachers and the algorithms compared to the teachers and the rest of the teachers. This suggests that algorithms produce routes with the same length of subsequences common to teacher-produced routes as other teachers do.

Figure 45 illustrates the significance, $p=.023$ for Set. This figure shows that routes generated by any Approach for Set 3 shared significantly proportionally shorter subsequences with the teachers than the routes generated for the other Sets.

Table 18 also shows $p=.022$ for Approach. The main effect of Approach is illustrated in Figure 46 indicating that the teachers produced fewer common subsequences between themselves as opposed to the teachers and the algorithms.

6.2.2.3 Discussion of Edit Distance Scores

Table 19 shows descriptive statistics for Ed between teacher routes and those generated by the approaches. Figure 47 illustrates these figures and suggests edit distance results between teachers and their peers are less than between teachers and the algorithms. This similarity is supported by $p<.01$ for Approach, shown in Table 20. Figure 49 shows significant difference between T and BF.

Set also has a significant effect $p=.019$. Figure 48 shows the main effect of Set, and suggests that Set 1 had significantly lower mean edit distances than Sets 2 and 3.

Some of the differences between the Ed results and those of Sst and Ssq can be explained by the variation in lengths of routes made by the teachers. Sst and Ssq do not take into account relative route length, whereas Ed does. Set 3 had the greatest number of ILOs offered to teachers, and teachers were instructed to leave out any ILOs they believed unnecessary. The algorithms produced uniform route lengths as governed by the ILO network. A baseline edit distance is constant for each teacher and any algorithm: if the teacher makes a route of 4 ILOs, and the algorithms a route of 8, then there will always be an Ed of at least 4. The teacher routes can have more similar lengths to other teacher routes, and as such, a lower edit distance for the T Approach in Set 3.

6.2.2.4 Summary of Discoveries

The purpose of this trial was to investigate whether there are significant differences between the routes of BF/DF algorithms and teachers, compared to the differences between teachers and other teachers. These results indicate that the algorithms were not significantly different to teachers. All of the approaches produced routes with similar LC Sst. The LC Ssq difference in approaches were significant however, as shown in Figure 46, it is the teachers' differences between themselves, as opposed to differences with the algorithms. Edit distance showed significantly more agreement between teachers than between teachers and algorithms, but this is due, in part at least, to issues with the metric and route length as discussed in 6.2.2.3 .

BF and DF, with minor exceptions, were not distinguishable for any of the sets or metrics. This indicates that the metrics may not be sufficiently sensitive to detect differences, or that the sets were not large enough to generate significantly different routes. Both algorithms produced routes constrained by the network. The teachers had no such constraints, and potentially could have produced routes very differently to the algorithms. Despite the effectively infinite possibilities (the teachers were invited to create custom cards/ILOs if desired), the teachers produce routes that were not significantly different to those produced by algorithms.

Set, and therefore *what* and *how much* is being taught, has an effect. Set 3 showed less agreement between any of the Approaches and the teachers in terms of common substring length and common subsequence length. The edit distance between teachers and the rest of the teachers was lower, indicating more similarity, again due

in part to the variation in teacher route length, and the algorithm fixed route length. However, the interaction of Approach and Set was not significant for any metric.

6.2.3 Limitations of Experiment 2

The number of participants studied in Experiment 2 was not enough to provide sufficient degrees of residual freedom to perform a multivariate analysis of variances. Such an analysis would have shown interactions between approaches and sets more clearly.

The ILO subnetworks each set was derived from differed in size, subject matter type, and topography. This may have caused an overstatement of the effect of set on approach/teacher difference. More sets, and more-similar sets, should have been examined to mitigate this effect.

The analysis was carried out with values calculated from the raw output of the analysis of the routes. This meant that values derived from common substring and subsequence lengths of 1 were included. Substring and subsequence lengths of 1 are meaningless and should have been adjusted to 0. Analysis of values based on lengths above a threshold (say, lengths of 3 and above) may have provided results that are more informative. Similarly, results from subsequence analysis should have been reduced by 1, to account for the fact that target nodes were specified to the participants, and so are common to the routes, and in identical positions at the end of the routes.

6.3 General Limitations

The experiments in this thesis were conducted with small sample sizes to evaluate the models suggested. The studies were performed with relatively few ILOs, and in single sessions. ILO-informed systems intended for self-directed learners would be used over long periods and could support thousands of ILOs. This thesis is a pilot study - more research in authentic settings is required to evaluate practicality of a larger scale system.

Experiment 1 was carried out with university graduates or undergraduates. Experiment 2 was carried out with teachers who taught either privately or in mainstream schools. No experiments were carried out with learners with non-typical needs. ILOs are age-blind and culturally indifferent – the behaviour of “solving simultaneous equations” is the same whether the learner is eight or eighty, or in a privileged English preparatory

school or a developing country's slum, though in such cases, the teaching resources used would probably be different. Learners at extremes of the age spectrum, or learners with learning difficulties have different needs. ILO-informed systems may be useful for such learners, but their suitability is not in the scope of this project.

6.4 Summary

This chapter explored the results presented in Chapter 5, explaining results and connotations in more detail.

Experiment 1 evidenced that non-subject-matter experts could interpret ILOs, effectively route using an ILO network, and could position themselves on an ILO network.

Experiment 2 showed that the algorithmic routes generated were comparable to the routes generated by teachers.

This was accompanied with a discussion of the limitations of the experiments, and suggestions for improvements should the experiments be repeated in the future.

The next chapter summarises the findings of this thesis, integrating the results found with the state of the art in the field.

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7. Summary and Conclusions

This chapter concludes this thesis, providing a summary of the content and results, and discusses the potential of ILO informed systems. The following chapter, Chapter 8, discusses future work to develop this potential.

7.1 Summary

Chapter 1 introduces the research area contextualising this thesis and defines the scope of the project.

Chapter 2 explores teaching and learning, with a focus on self-directed learning, which takes place in all learning. This chapter discussed ILOs; what they are, how they can be networked and how routing through ILO networks can work. ILOs were contextualised in terms of historical practice and contemporary developments. ILO networks are comparable to other approaches, such as KST and Khan Academy's "Knowledge Map".

Chapter 3 discusses the content identified in Chapter 2, elaborating learner and teacher roles, and explaining the difficulties in routing experienced by self-directed learners. Chapter 3 introduces models for ILOs, ILO networks and Traversal Algorithms which are used in Chapter 4. Chapter 4 stated and elaborated the research questions, namely:

- 1) *To what degree do routes of ILOs generated by algorithms differ from sequences of ILOs generated by teachers?*

This is broken into sub-questions.

Given the models described in Sections 1.2 and 3.2.3:

- 2) *Do non-subject matter experts understand and correctly interpret the specification and model for ILOs?*
- 3) *Do non-subject matter experts understand and correctly interpret the specification and model for ILO Networks?*

- 4) *Can non-subject matter experts relate the model to their own capabilities, that is, can they self-report their proficiency in a subject area in terms of ILOs?*

Chapter 4 also showed the design of the methodology by which the research was carried out for both sets of experiments in order to answer those questions. Chapter 5 detailed the results of those experiments, and Chapter 6 discussed the implications.

7.2 Conclusions

The evidence produced in Experiment 1 addresses research questions 2-4. The results suggest that non-subject matter experts can interpret ILOs accurately enough to choose relevant resources, can effectively route through unfamiliar subject matter using an ILO network, and that they can position themselves on an ILO network.

Findings in Experiment 2, addressing research question 1, were varied, but there is evidence that the BF and DF algorithms generated routes that were not significantly different to teachers when compared with other teachers. This lends credence to the proposal that algorithms could route in a similar way to teachers.

These results show that ILO-informed systems have the potential to be developed and be useful in the field of education. Automated routing through ILOs, especially when combined with resources that support those ILOs, has the potential to lower barriers of entry for self-directed learners. Facilitating self-directed learning could bring about changes in how education is pursued both domestically and abroad. Several charities and governments of developing countries are prioritising computer technology in their education systems. With such equipment, and appropriate support, it is possible that keen learners from across the world could achieve educational outcomes beyond what present teaching infrastructures can support.

7.2.1 Contributions

This work focussed on exploring algorithms routing through ILO networks, and how similar the output of those algorithms is to output generated by teachers. In order to do this, a formal, well-defined sample ILO network was created. By exposure to learners and teachers, it has been validated and shown to be sufficiently accurate as to be useful in the contexts of the experiments. This work has evaluated learner's capabilities in interpreting ILO definitions, showing that learners were able to interpret individual ILO descriptions, even if they were not able to achieve the ILO themselves.

The study also investigated the learners' abilities to position themselves on an ILO network, and to create routes through unfamiliar content with a network. Learners responded positively to the idea of using ILO networks to model academic courses.

7.3 Future Work

This thesis has indicated that foundational algorithms can route through ILO networks in a way comparable to conventional teaching practices. This topic could be developed further in a number of ways:

7.3.1 More topics, More Teachers, More Algorithms

The experiments performed and described here involved ten teachers, four learners, and a network of around 100 ILOs. The subject was limited to music theory. Further experiments with larger networks of different subject matter types would provide additional evidence as to the efficacy of the proposals.

A major point of investigation might involve different algorithms. The algorithms used in this work were the foundational breadth and depth first approaches. Section 1.2.3 describes possible approaches that take the content and structure into account. Alternatively, the routes generated by teachers could be analysed to identify patterns present. Section 7.3.2 discusses involving learners, and any algorithms, whether developed from properties of the ILO network or from teachers, should be evaluated by how effectively they serve learners. It is entirely possible that algorithms could outperform teachers in terms of effective routing.

7.3.2 Involving Learners

This work has focussed on the routing aspect of teaching. Teaching exists as a service and facilitation for learning, and so future work should examine the experiences of learners interacting with ILO systems and the subsequent performances of those learners.

7.3.3 Supporting software

The previous sections have addressed future work from a research standpoint. From a logistical view, a major issue in need of addressing is the lack of software for authoring, building, validating, representing, manipulating and simply using ILO

networks. This work was undertaken with a somewhat “brute force” approach to aspects of the ILO network, and the time taken to simply author and arrange the ILO network layout was not cost-effective. Future work in this area would undoubtedly benefit from a front-end investment into developing a suite of software tools configured for the particular requirements of ILO network modelling and manipulation.

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Appendix A. Experiment 1 Participant Pack

FPAS Participant Information Sheet

Study Title: Learner interactions with Intended Learning Outcomes

Researcher: Teresa Binks

Ethics Reference Number: 6219

Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.

What is the research about?

This study is part of a doctoral thesis work. The researchers name is Teresa Binks, PhD student. In this study you will be asked to perform various operations with Intended Learning Outcomes, to determine how easy or difficult it is to use our model.

Why have I been chosen?

This is an “opportunity sample”. You have been invited because you were willing to attend.

What will happen to me if I take part?

This study will be completed in one sitting; there is no follow up. You will be asked to answer a selection of quiz style questions, and to examine a diagram, relate it to your own experience and identify paths within it. It is estimated that this session will take about 40 minutes. It will not exceed an hour.

Are there any benefits in my taking part?

This study is not financially compensated, but you may learn new things about music theory.

Are there any risks involved?

There are no more risks than in an everyday office or cafe environment.

Will my participation be confidential?

Results from this experiment will be anonymised at source; your name will not be linked directly or indirectly with any data gathered. The researcher conducting the session will know your identity, but any notes taken will not be linked to you

What happens if I change my mind?

You have the right to withdraw at any time with no repercussions.

What happens if something goes wrong?

In the unlikely case of concern or complaint, you can contact:

The researcher: Teresa Binks, tb1206@ecs.soton.ac.uk, ext:27684

Her supervisor: Lester Gilbert, lq3@ecs.soton.ac.uk, ext:23831 with phone numbers I Dr Martina Prude, Head of Research Governance (02380 595058, mad4@soton.ac.uk)

Where can I get more information?

If you have any questions, please contact Teresa, tb1206@ecs.soton.ac.uk, ext:27684

CONSENT FORM (v0.1)

Study title: : Learner interactions with Intended Learning Outcomes

Researcher name: Teresa Binks

Ethics reference number: 6219

Please initial the box(es) if you agree with the statement(s):

I have read and understood the information sheet v0.1 and have had the opportunity to ask questions about the study.

☐

I agree to take part in this research project and agree for my data to be used for the purpose of this study

☐

I understand my participation is voluntary and I may withdraw at any time without my legal rights being affected

☐

I am happy to be contacted regarding other unspecified research projects. I therefore consent to the University retaining my personal details on a database, kept separately from the research data detailed above. The 'validity' of my consent is conditional upon the University complying with the Data Protection Act and I understand that I can request my details be removed from this database at any time.

☐

Data Protection

I understand that information collected about me during my participation in this study will be stored on a password protected computer and that this information will only be used for the purpose of this study. All files containing any personal data will be made anonymous.

Name of participant (print name).....

Signature of participant.....

Date.....

Overveiw

This prototype study aims to determine how people react to, and interpret, a specific way of writing educational outcomes or aims.

In this study, educational aims are formally called Intended Learning Outcomes (ILOs). They are likely to be different than ILOs that you may have come across in the past.

Intended Learning Outcomes are written as behavioural descriptions. This means that the ILO must be demonstratable, there has to be some visible behaviour. This is so that a student can be marked on their performance.

In this study, you cannot be wrong! This study tests how easy this work is to use, so if you find it hard, it is the deficiency of the specification and model, not your capabilities. If you can “think out loud” while you are working, that would be very helpful to the researcher, so feel free to talk to yourself.

Section 1

The first section of this study tests how effective the specification used for writing the ILOs is.

You will be asked to read an ILO description, and then choose the resource that best addresses that description.

The resource will either be a explanatory (telling) resource, like an instructive sentence or diagram, or an inquisitory (asking) resource, like a quiz item or something to fill in the blanks.

Don't be concerned if you don't know the subject matter in the ILOs. This isn't a test of your knowledge, it is a test of our specification, and how easy it is for people without subject knowledge to use.

Please read the ILO descriptions carefully, and choose the resource that best matches the behaviour the ILO is describing. You may choose more than one option if appropriate.

Item 1

define Time Signature

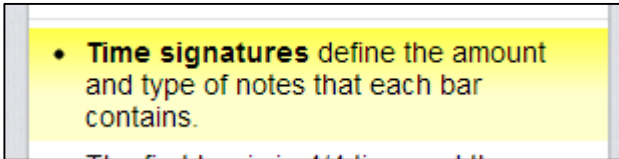
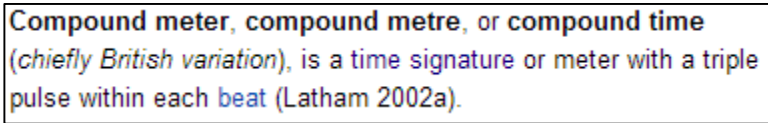
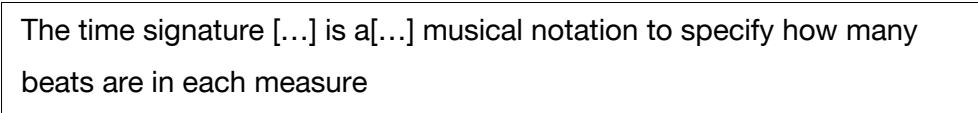
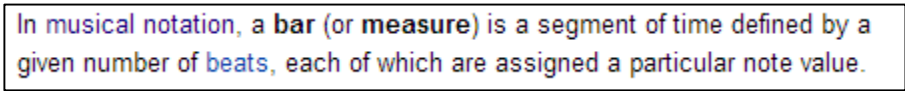
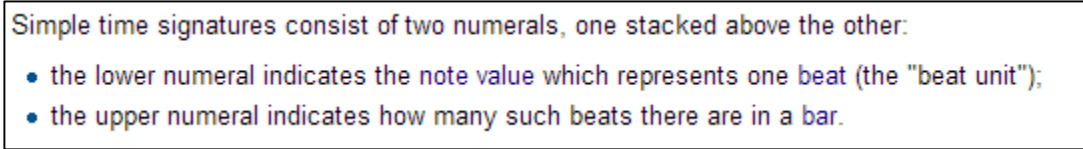
More info

By the end of the lesson, the student will be able to Define Time Signature.

Id	002
String	Define Time Signature
Level	Recollection
Communication	Select from options

Concept	id	c001
Prose	Time Signature	
name:	Time Signature	
is a	notation	
Where	definition	specifies beats in measure
	topNumber	Specifies number of beats
	bottomNumber	Specifies types of beat

Options for Item 1

- a. 
 - **Time signatures** define the amount and type of notes that each bar contains.
- b. 
Compound meter, compound metre, or compound time (*chiefly British variation*), is a **time signature** or meter with a triple pulse within each **beat** (Latham 2002a).
- c. 
The time signature [...] is a [...] musical notation to specify how many beats are in each measure
- d. 
In musical notation, a **bar** (or **measure**) is a segment of time defined by a given number of **beats**, each of which are assigned a particular note value.
- e. 
Simple time signatures consist of two numerals, one stacked above the other:
 - the lower numeral indicates the **note value** which represents one **beat** (the "beat unit");
 - the upper numeral indicates how many such beats there are in a **bar**.

Item 2

draw the sharp(#) symbol, given the name “sharp symbol”

More info

By the end of the lesson, the student will be able to draw the sharp(#) symbol, given the name “sharp symbol”.

Id	127
String	Draw 'Sharp' symbol
Level	Comprehension
Communication	Draw

Concept	id	c017
Prose	sharp	
name:	sharp	
is a	musical concept	
Where	definition	higher in pitch by a semitone
	effect	raises the pitch of the note the sharp is applied to by one semitone
	symbol	#

Options for Item 2




- a.

“What does the sharp (#) symbol do?”
- b.

The sharp symbol raises the pitch of a note by a semitone.
- c.

A **flat sign** means “the note that is one half step lower than the natural note”.
- d.

Key signatures also can make all notes for sharps or flats consistent for the whole song.
- e.

Sharp Symbol	Natural Symbol	Flat Symbol
		

Item 3

identify notes on the treble clef

More info

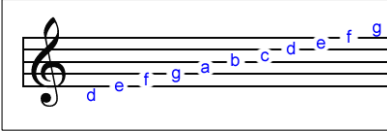
By the end of the lesson, the student will be able to identify notes on the treble clef.

Id	026
String	Identify notes on treble staff
Level	comprehension
Communication	write

<i>Concept</i>	<i>id</i>	<i>c002</i>
Prose		Notes on treble staff
name:		Notes on treble staff
is a		notation
Where	firstLine	e
	firstSpace	f
	secondLine	g
	secondSpace	a
	thirdLine	b
	thirdSpace	c
	forthLine	d
	forthSpace	e
	fifthLine	f

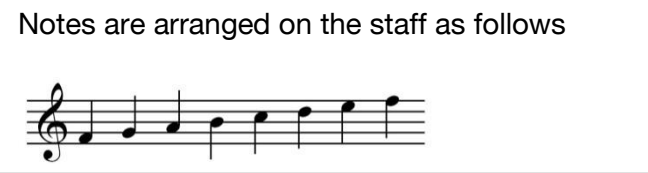
Options for Item 3

a.



b.

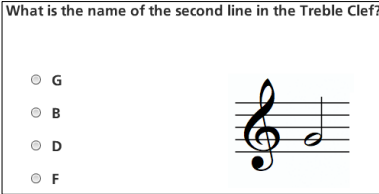
Notes are arranged on the staff as follows



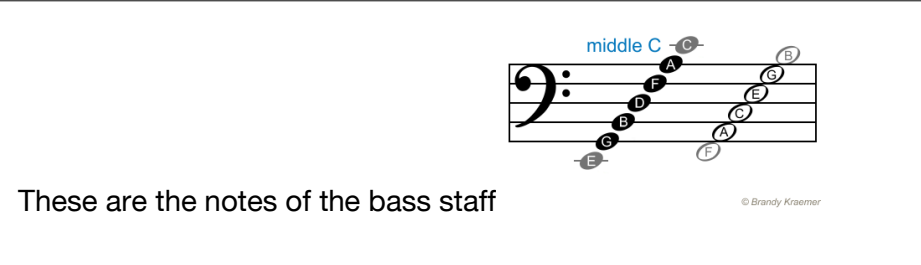
c.

What is the name of the second line in the Treble Clef?

- ☐ G
- ☐ B
- ☐ D
- ☐ F



d.



These are the notes of the bass staff

© Brandy Kraemer

e.

Line Notes: Starting on the lowest of the five lines, E,G,B,D,F.
Use the phrase, “Every Good Boy Does Fine,” to help you remember.

Space Notes: Starting in the first space, F,A,C,E.
Use the word FACE to help you remember the notes of the spaces.

Item 4

demonstrate chord inversion

More info

By the end of the lesson, the student will be able to demonstrate chord inversion.


Id	075
String	Demonstrate Chord Inversion
Level	application
Communication	write

Procedure	id	p002
name:		Invert Chord
Prose		
situation:		Given chord
goal:		invert chord
steps:		Given Chord in root position Given inversion number/ordinal Start with the chord. Identify the bass note. Move the bass note up by one octave. The chord is now in first inversion Move the (new) bass note up by one octave. The chord is now in second inversion. repeat until target inversion is achieved.

Options for Item 4

- a.

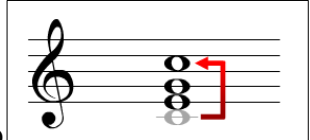
If the third of the triad is in the lowest voice the triad is the 1st inversion.



1st Inversion
- b.

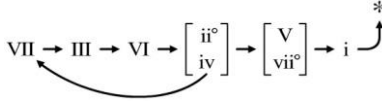
A chord's *inversion* describes the relationship of its bass to the other tones in the chord. For instance, a C major triad contains the tones C, E and G; its inversion is determined by which of these tones is used as the bottom note in the chord
- c.

In an inverted chord, the root is not in the bass (i.e., is not the lowest note). The inversions are numbered in the order their bass tones would appear in a closed root position chord (from bottom to top).
- d.



To invert, move the bass note one octave up
- e.

This diagram shows common chord progressions:



Item 5

state Tone/Semitone pattern for Natural Minor Scale

More info

By the end of the lesson, the student will be able to state the Natural Minor scale pattern.

Id	048
String	state Tone/Semitone pattern for Natural Minor Scale
Level	recollection
Communication	write

Fact	id:	f005
name:	Natural Minor scale pattern	
Subject	Natural Minor scale pattern	
Relationship	is	
Object	TSTTSTT	
Prose:	The Natural Minor scale is constructed with the pattern TSTTSTT	

Options for Item 5

- a.

The scale <D Eb F G A Bb Cb D> is what type of scale?
Major
minor
diminished

- b.

The notes of the harmonic minor scale are the same as the natural minor except that the seventh degree is raised by one semitone, making an augmented second between the sixth and seventh

- c.

The natural minor scale follows the sequence of steps:

whole, half, whole, whole, half, whole, whole
(tone, semitone, tone, tone, semitone, tone, tone)

- d.

Some people find it easier to write minor scales by converting a major scale to a minor scale. Here's how it works: Start with a major scale, then lower the 3rd, 6th, and 7th by a half step.

When lowering scale degrees 3, 6, and 7, you don't necessarily add a flat symbol. Lowering means doing whatever

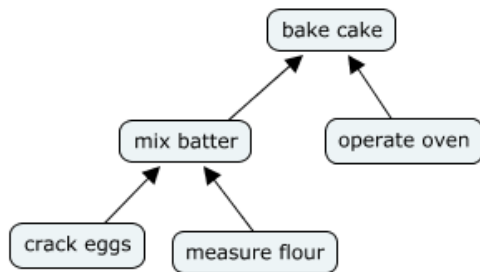
- e.

What are the notes of C Minor?

Section 2

The second section uses ILOs in an interconnected network.

This model is based on the idea of “probably necessary” connections.



In this example to the left, you probably need to be able to crack eggs and measure flour before you can mix batter. And you probably need to be able to mix batter and operate the oven before you can bake the cake.

This phase of this study tests how easily this kind of network can be interpreted, and gives some idea of missing links and nodes in the structure.

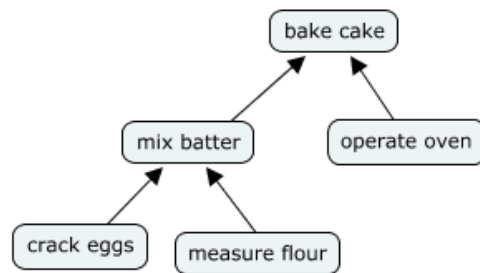
Examine the structure provided. Use colored pens to mark nodes, one colour for ILOs that you are reasonably confident that you could perform. Mark, in a different colour, ILOs that you definitely couldn't do.

Section 3

The second section uses the same network of ILOs, and tests how “readable” the structure is.

With a well developed structure, it’s conceivable that a student could route themselves from basic knowledge, up to advanced concepts. It’s also conceivable that a computer could do the routing for them, and pass on appropriate resources for each ILO.

This section asks you to make “routes” through the network.



For example, using the cake structure. Sam wants to bake a cake, and can crack eggs.

A possible route would be:

crack eggs

measure flour

mix batter

operate oven

bake cake

<p>An alternative would be:</p> <p><i>crack eggs</i></p> <p>operate oven</p> <p>measure flour</p> <p>mix batter</p> <p><i>bake cake</i></p>	<p>But couldn't be</p> <p><i>crack eggs</i></p> <p>mix batter</p> <p>operate oven</p> <p>measure flour</p> <p><i>bake cake</i></p>
---	--

Your turn:

Given the same map from section 2, identify a sequence that will achieve the target node, given the starting node.

Starting node: “005, Define Staff”

Target node “042, Identify notes on the combined staff”

Starting node: “031, Define Compound time”

Target node “076, State note duration”

Starting node: “054, Define octave”

Target node “190, Recall semitones in Perfect fifth”

Summing up

Thanks for taking part in this study. If you have any feedback, or ideas, or questions, go for it!

Appendix B. Experiment 1 Phase 1 Data

B.1. Participant 1

Note: An unnoticed printing error rendered Items 4 and 5 unusable. Options were missed on two remaining Items. Participant 1's results for Section 1 were not included in the statistical analysis.

Item 1: [options "c" and "e" failed to print] Participant selected "Time signatures define the amount and type of notes that each bar contains"

Item 2: Participant selected pictorial representation of sharp symbol.

Item 3: [options b, d and e failed to print] Participant selected diagram of letter on the staff.

Item 4: Failed to print

Item 5: Failed to print.

B.2. Participant 2

Item 1: Participant selected "In musical notation, a bar (or measure) is a segment of time defined by a given number of beats, each of which are assigned a particular value."

Item 2: Participant selected pictorial representation of sharp symbol.

Item 3: Participant selected diagram of letters on the staff and "What is the name of the second line in the treble clef?"

Item 4: Participant selected "To invert, move the bass note one octave up".

Item 5: Participant selected "The natural minor scale follows the sequence of steps: [...] and "What are the notes of C Minor?"

B.3. Participant 3

Item 1. Participant selected “The time signature [...] is a [...] musical notation to specify how many beats are in each measure”.

Item 2. Participant selected graphical representation of sharp symbol,

Item 3. Participant selected diagram of letters on the staff.

Item 4. Participant selected “A chord’s inversion describes [...]”. This is the definition rather than the process.

Item 5. Participant selected “Some people find it easier [...]”, selecting the conversion process rather than a fact statement

Participant completed this section particularly slowly, paying great attention to the tables below the ILO. When this was queried at the end of the study, the participant said they’d paid little attention to the ILO phrase, and had focussed on the subject matter table.

B.4. Participant 4

Item 1. Participant selected “Time signatures define the amount and type of notes that each bar contains.” and “Simple time signatures consist of two numerals [...]”. The participant indicated that they were interpreting the content from the subject matter table rather than focussing on the ILO.

Item 2. Participant selected graphical representation of sharp symbol, and indicated that they used the ILO as a final verification of what the desired learner behaviour was.

Item 3. Participant selected diagram of letters on the staff.

Item 4. Participant selected “To invert, move the bass not one octave up”. They indicated that they were choosing a pictorial representation of the process, suggesting they had noticed the subject matter type either from the table heading, or from the algorithmic format.

Item 5. Participant selected “The natural minor scale follows the sequence of steps:
[...].”

Appendix C. Experiment 1 Phase 2 Data

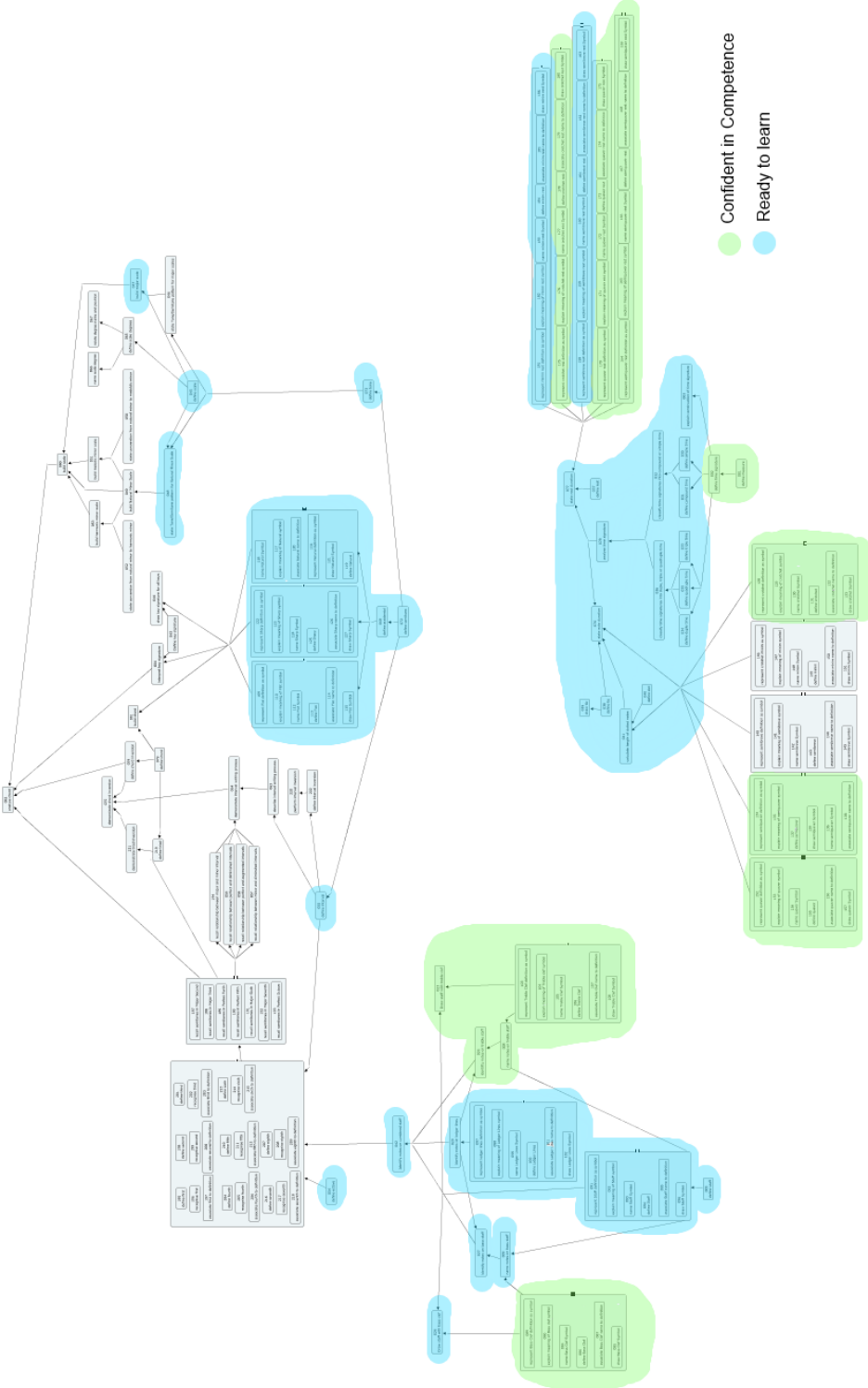


Figure 50 Participant 1 positioning

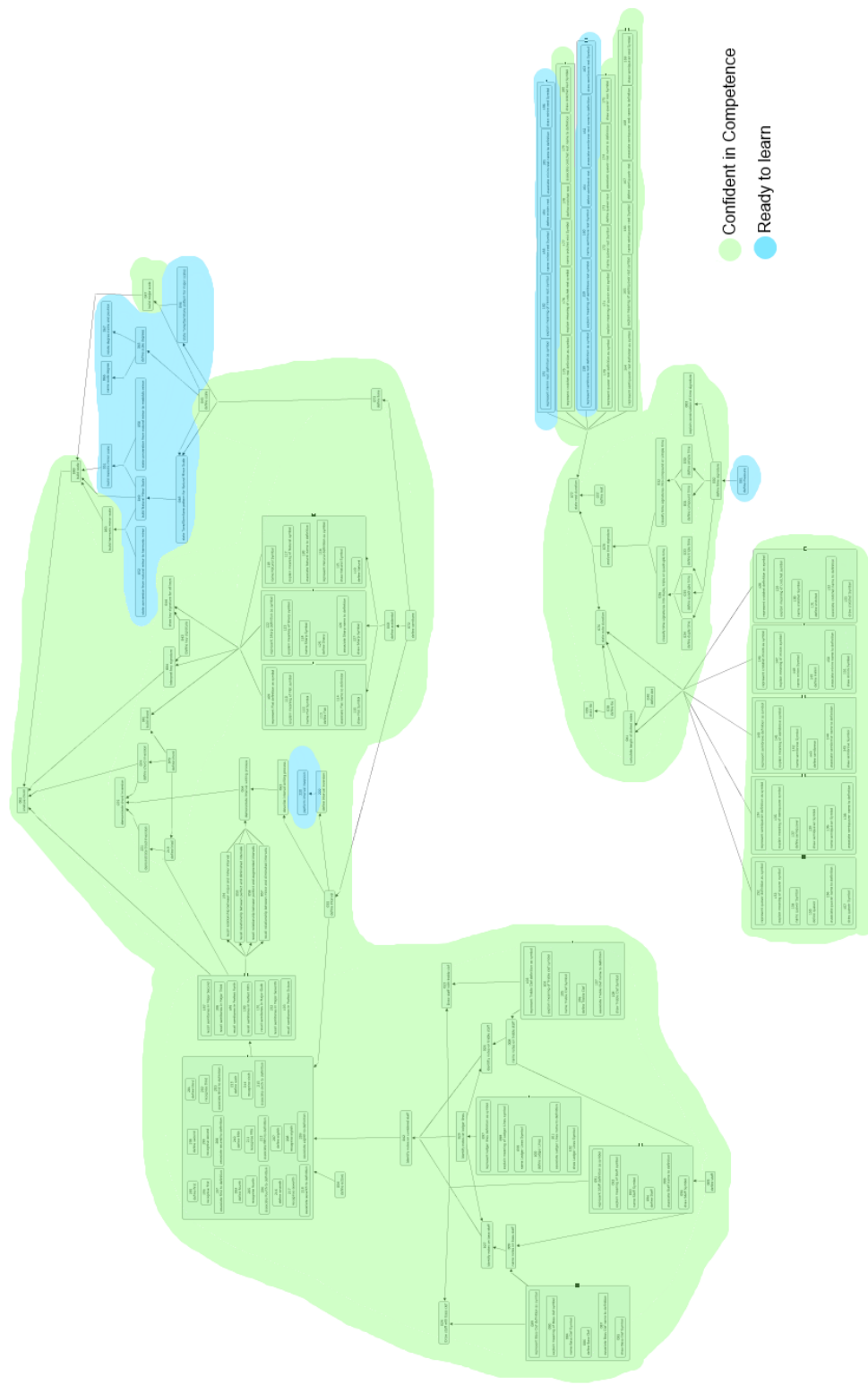


Figure 51 Participant 2 positioning

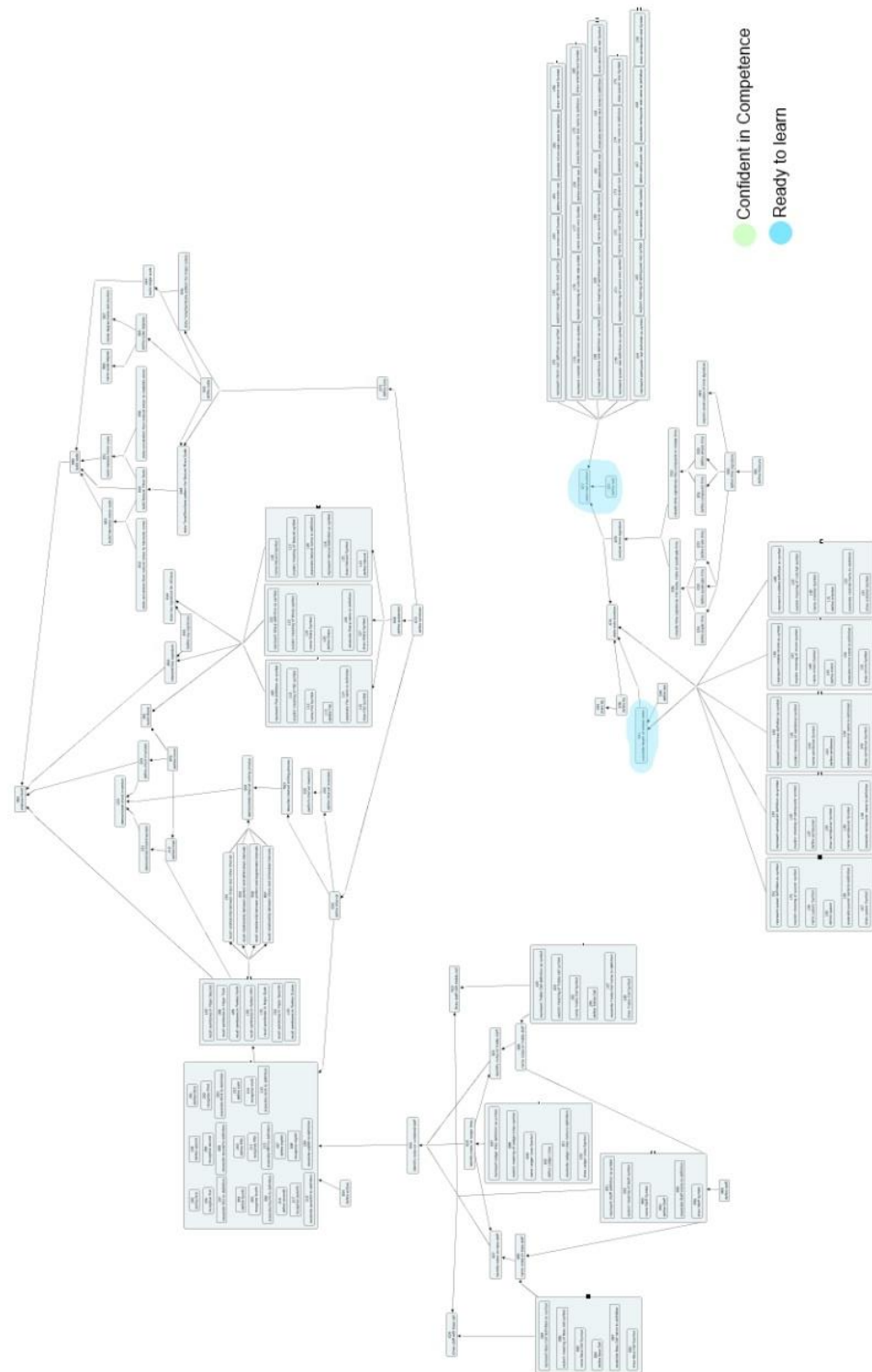


Figure 52 Participant 3 positioning

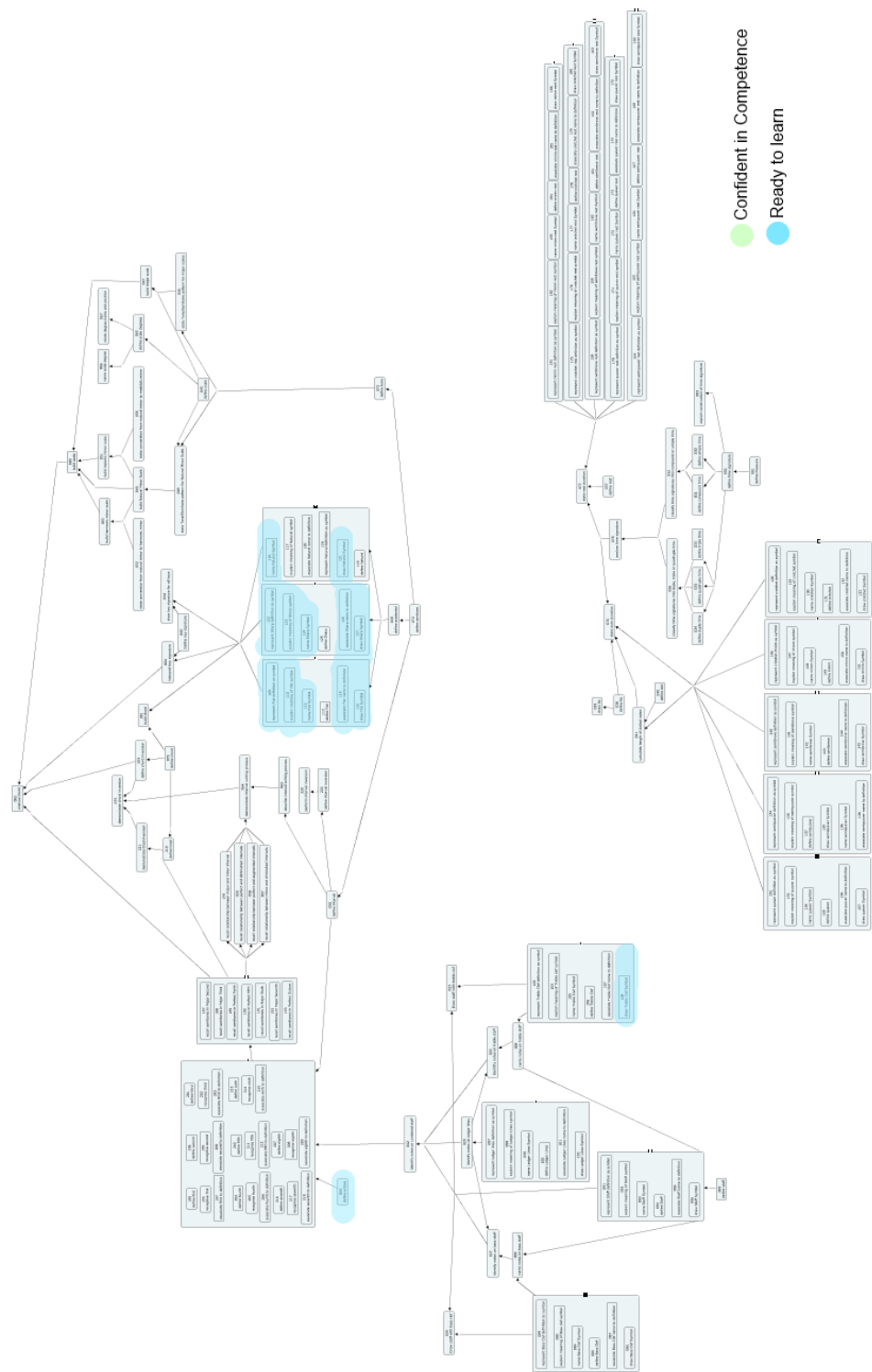


Figure 53 Participant 4 positioning

Appendix D. Experiment 1 Phase 3 Data

D.1. Participant 1

- “005, Define Staff” - “042, Identify notes on the combined staff”
005, {091, 092, 093, 094, 095, 096}, {089, 090, 084, 086, 087, 085}, {103, 104, 105, 106, 107, 108}, {097, 098, 099, 100, 101, 102}, 029, 009, 027, 008, 026, 024, 023, **042**

024 and 023 were included in the path, but were not necessary in the network to achieve the target node.

- “031, Define Compound time” - “076, State note duration”
031, 030, 032, {034, 035, 033, 036}, 078, {128-138, 140-157}, 040, 041, 038, **076**

The participant created collections and implied the order would go in the direction of the arrows if there was any necessary hierarchy. The subject did not include non-necessary nodes like the first time, even though the layout was similar.

- “054, Define octave” - “190, Recall semitones in Perfect fifth”
(As in first route), 072, 055, 195-218, 190

The subject independently chose to reuse the sequence from section 1. This subject was the only one to include the previous route, and the only one to include the interval nodes to the right.

In all three sequences, the subject sequenced following the arrow rules.

D.2. Participant 2

- 005, Define Staff” - “042, Identify notes on the combined staff”
005, 092, 086, 090, 009, 106, 104, 008, 100, 099, 029, 027, 026, **042**.

The subject did this very carefully, and examined the diagram closely. They

Appendix D

made several revisions, and asked lots of questions, pertaining to whether the minimal route was desired, who the target audience was etc. They also spotted apparent duplication, and during one revision used groups, but specifically dis-included certain nodes. The resulting route achieves the target node. It includes some nodes that may not technically be needed, but that are almost implicit in other nodes i.e. “099, name ledger lines symbol” and “100, define ledger lines”. An alternative would have been to include the single node: “098, explain meaning of ledger lines symbol”.

This is indicative of the need to either clarify the ILOs better, or to train those interpreting them.

- “031, Define Compound time” - “076, State note duration”
031, 030, 032, {128-138, 140-157}, 040, 041, 038, {033-035}, 036, 078, **076**

During this route, the subject paid more attention to the diagram and linking arrows, completing the route far faster than the previous one, with no revisions. The subject did not exclude any nodes from groups, even though they were strictly unnecessary. The researcher got the impression that the subject believed that the cognitive load of learning those additional grouped nodes was not significant enough to warrant their removal.

- “054, Define octave” - “190, Recall semitones in Perfect fifth”
054, 210, 211, 212, **190**

The subject provided the minimal route and specifically honed in on the words related to the target ILO. The subject did not explicitly include the subset of nodes already sequenced in the first question, nor did they include the interval nodes to the far right.

D.3. Participant 3

- “005, Define Staff” - “042, Identify notes on the combined staff”
005, (094, 092, 093, 095, 096, 091), {(086, 090, 084, 085, 087, 089), (106, 104, 105, 108, 107, 103)}, {009, 008}, {027,026}, {024, 023}, **042**

This participant was the first to include entire DT groups, but to also sequence them. That is, they made sub-routes. This participant also made sets of nodes that were not spatially close to each other, but that had the same template

(e.g. “identify notes on bass staff” and “identify notes on treble staff”). The participant indicated that these could be done in any order. The route included non-necessary nodes.

- “031, Define Compound time” - “076, State note duration”
031, {034, 035, 033, 030}, {036, 032}, 078, **076**

Participant ignored arrows to the left of the target node, and focussed only on the path from the starting node that was on the right of the target node. The route was missing requisite nodes.

- “054, Define octave” - “190, Recall semitones in Perfect fifth”
054, 210, 211, 212, **190**

Participant made no reference to note-staff section, nor to arrows from interval section of map.

The participant applied a form of logic for determining the routes. They interpreted the behaviour, and formed routes around advancing levels of behaviour that referred to similar subject matter, even though they did not comprehend the subject matter.

D.4. Participant 4

- “005, Define Staff” - “042, Identify notes on the combined staff”
005, {091, 092, 093, 094, 095, 096}, {089, 090, 084, 086, 087, 085}, 009, {103, 104, 105, 106, 107, 108}, 008, 024, 023, {097, 098, 099, 100, 101, 102}, 029, 027, 026, **042**

Participant included extra nodes. When this was queried after the session, the participant indicated it was due to spatial layout. The subject also expressed that they had not even noticed lines that were originated from the bottom corners of a box (in an upwards direction). As the participant was going up the structure, they didn’t notice any lines originating from that upwards direction.

The participant spent considerable time examine the first DT collection they came across, before deciding that the concepts were too interlinked to separate, and indicating that they were an “any order” subgroup.

- “031, Define Compound time” - “076, State note duration”
031, 030, 032, 034, 035, 033, 036, 078, **076**

Appendix D

Participant ignored arrows to the left of the target node, and focussed only on the path from the starting node that was on the right of the target node. The route was missing requisite nodes.

- “054, Define octave” - “190, Recall semitones in Perfect fifth”
054, 211, 212, 190

The participant actively read the ILO nodes and interpreted their subject matter, debating on whether a learner would have to be able to define fifth in order to recognise one. The participant did not include any nodes from the first route, nor the interval nodes from the right.

Appendix E. Experiment 2 Participant Pack

This Appendix contains the documentation presented to participants in Experiment 2.

Participant Information

Ethics reference number: ERGO/FoPSE/7318	Version: 1	Date: 2013-08-19
Study Title: Teacher interactions with ILO networks		
Investigator: Teresa Binks		

Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form. Your participation is completely voluntary.

What is the research about? This is a student project which aims to evaluate a data model, and algorithms that work with it. At the end of the study, you can request the study findings and see how your data was used.

Why have I been chosen? You have been approached because you hold relevant experience. You are part of an opportunity sample.

What will happen to me if I take part? You will first be asked to answer some questions about how you structure content when teaching music theory. You will then be asked to sequence some cards to represent a teaching progression. Lastly, you will be offered a chance to critique a music theory intended learning outcome network. The session will last less than an hour.

Are there any benefits in my taking part? Your participation will help further this research. You may find the different representations used useful for you or your students.

Are there any risks involved? There are no particular risks associated with your participation

Will my participation be confidential? All data collected is anonymous . It will be held on a password protected computer, and used only for the purposes of this study. It will destroyed by deletion of the files once their purpose is served. As this data is anonymous, it will not be possible to withdraw it after the study.

What happens if I change my mind? You may withdraw at any time and for any reason. You may keep any benefits you receive.

What happens if something goes wrong? Should you have any concern or complaint, contact me if possible (investigator e-mail tb1206@ecs.soton.ac.uk), otherwise please contact the FoPSE Office (e-mail fpse@soton.ac.uk) or any other

Appendix E

authoritative body such as Dr Martina Prude, Head of Research Governance (02380 595058, mad4@soton.ac.uk).

Interaction sheet.

Thank you for agreeing to participate in this experiment. This study is about teaching music theory, and specifically investigates the order in which teachers teach music theory concepts.

Through different stages in this experiment, you will be asked to work with Intended Learning Outcomes. Though the term ‘intended learning outcome’ has many definitions throughout the educational world, in this context, and for the entirety of this study, it has a very specific meaning.

Intended Learning Outcomes are written as **behavioural descriptions**. This means that the ILO must be **demonstratable**, there has to be some visible behaviour, like **writing**, or **building**, or **identifying** (by pointing etc). This is so that a student can be marked on their performance.

In this study, you cannot be wrong! This study tests our modelling and ordering of outcomes, so if you find it confusing or just plain incorrect, it is the deficiency of the specification and model, not of you or your understanding of the technical specifics of this project. If you see errors, or think something is missing, please tell us! If you can “think out loud” while you are working, that would be very helpful to the researcher, so feel free to talk to yourself.

Consent Form

Ethics reference number: ERGO/FoPSE/7318	Version: 1	Date: 2013-08-19
Study Title: Teacher interactions with ILO networks		
Investigator: Teresa Binks		

Please ***initial*** the box(es) if you agree with the statement(s):

I have read and understood the Participant Information (version 1 dated 2013-08-19) and have had the opportunity to ask questions about the

☐

I agree to take part in this study and agree for my data to be used for

☐

I understand my participation is voluntary and I may withdraw at any

☐

Data Protection

I understand that information collected during my participation in this study is completely anonymous on a password protected computer and that this information will only be used for the purpose of this study.

Name of participant (print name).....

Signature of participant.....

Date.....

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Appendix F. Experiment 2 Phase 2 Data

The following tables show the routes produced by the teachers. The numbers are the ILO IDs. Where these numbers appear in quotation marks, the teacher created an ILO that was equivalent to an ILO already in the network, but not provided on a card. Where teachers created entirely new ILOs, these are shown as their full text in the tables.

F.1. Set 1

Participant	Sequence							
T1	"24"	046	045	072	073	047		
T2	045	073	072	046	042	047		
T3	045	046	072	008	047			
T4	045	073	072	046	008	009	042	047
T5	008	009	042	073	072	045	046	047
T6a	045	072	073	046	008	047		
T6b^a	045	073	072	046	008	047		
T7	045	008	072	073	046	047		
T8	008	009	045	073	072	046	047	
T9	045	072	073	046	008	047		
T10	008	073	072	045	046	047		
^a This participant independently stated two valid alternative paths. The second path was not used in the analysis as the differences in results were negligible.								

Table 21 Results of Set 1

F.2. Set 2

Participant	Sequence								
T1	277	043	240						
T2	"047"	277	042	043	279	278	240		
T3	277	278	043	068	008	240			
T4	043	008	068	277	009	042	240		
T5	008	009	042	068	279	277	278	043	240
T6	068	279	277	278	008	"046"	"047"	240	
T7	008	068	277	043	240				
T8	008	009	068	279	277	278	043	240	
T9	008	277	043	"047"	240				
T10	008	009	042	068	279	277	278	043	240

Table 22 Results of Set 2

Participant	Sequence												
T1	045	065	072	073	701	051							
T2	065	Adapt Major scale by lowering 3rd degree	Explain difference in ascending and descending	701	042	051							
T3	045	065	008	073	072	048	049	701	050	051			
T4	045	073	072	008	701	065	009	042	051				
T5	008	009	042	072	073	045	065	048	049	050	701	051	
T6	045	073	072	701	008	051							
T7	045	008	072	073	048	049	065	050	701	051			
T8	008	009	072	073	045	065	048	049	050	701	051		

T9	008	045	072	073	701	065	051					
T10	008	009	042	073	072	045	048	049	065	701	051	

Table 23 Results of Set 3

Appendix G. Experiment 2 Phase 2 Graphs

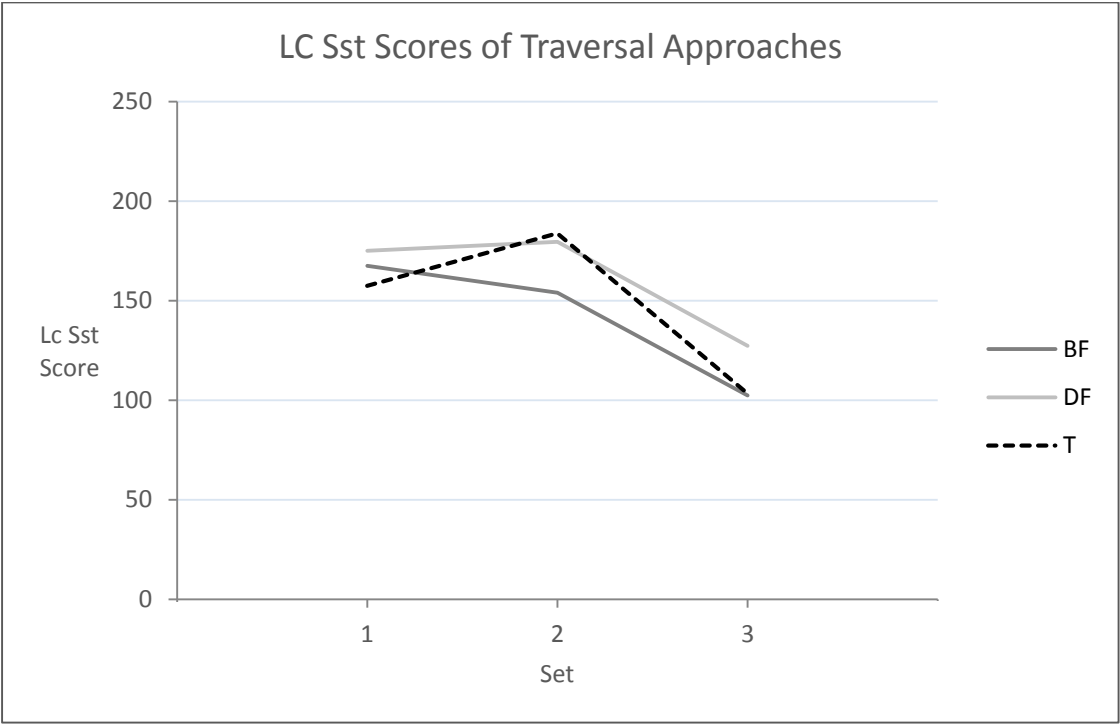


Figure 54 LC Sst of Traversal Approaches by Set

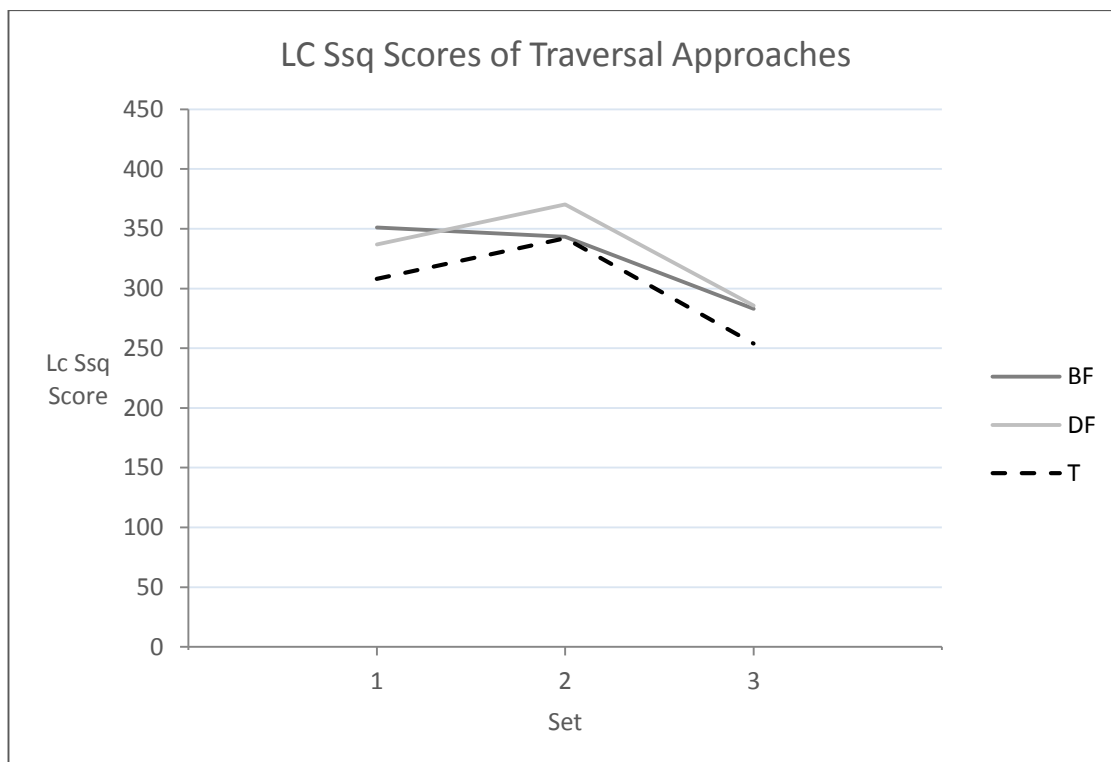


Figure 55 LC Ssq of Traversal Approaches by Set

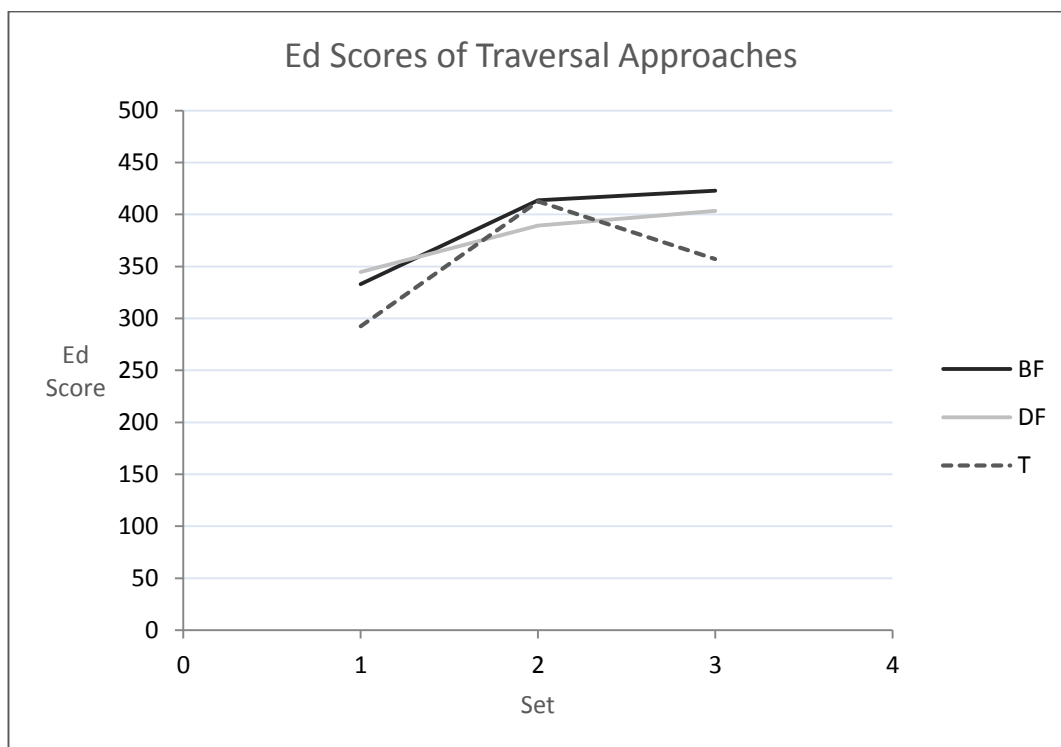


Figure 56 Ed of Traversal Approaches by Set

Appendix H. Competences

The field of competence is related to the field of ILOs. Generally, competences are defined similarly to ILOs, but with additional details, most notably details about context. Here context means the context of the learning outcome, not of the context that the learning activity takes place in.

Like ILOs, competences have many different definitions. Sampson & Fytros (2008) review several definitions of competence, they identify three dimensions that are common and therefore seem essential. These are Personal Characteristics, Context and Proficiency Level. Competencies are covered by other survey papers such as Draganidis & Mentzas (2006) who define competency in terms of category, competency, definition and demonstrated behaviour. Dubois (1998) states that competency modelling is the process of capturing the skills, knowledge and other properties that a worker needs to succeed in their tasks .

Work on linking context of behaviour with ILOs has been reported by Nichot, Gilbert & Wills (2010) . These two components, ILO and Context, form the basis for Nichot et al's definition of competences.

Stoof, Martens & van Merriënboer (2007) define competence, and include six dimensions: Level, Context, Relationships, Elements, Output and Kind.

Initially, this research focused on competences, and original work in the area of context is included in the appendices at 6.1. However, in the progression of the research, the focus moved away from competencies and into the domain of the more fundamental model of the ILO, upon which the models of competencies are based.

Zimmermann, Lorenz, & Oppermann (Zimmermann, Lorenz, & Oppermann, 2007) model context in 5 overlapping dimensions: individuality, time, location, activity and relations. With no examples in the text, it is not clear how useful or adaptable this model is. It is certainly broad, and perhaps the overhead of dealing with this breadth is that it is not feasible for lightweight applications. No formal data structure or fields or values are proposed in the paper, which precludes full evaluation.

Context has been explored in machine learning. (John McCarthy & Buvač, 1997) attempt modelling context using first order objects and predicates, for the purpose of representing context for AI systems. Contrary to the attempts at ILO templating (creating fields that must be filled by variables, the author assigns properties to context objects, rather than trying to predefine all the variable that could be included.

Work on context is prevalent in the literature, but the area still lacks any definitive works or standards. Several authors have tried to synthesise several contributions into coherent, generic models. (Zimmermann et al., 2007) (Kaenampornpan & O'Neill, 2004a) (Kaenampornpan & O'Neill, 2004b). It appears these new synthetic models have garnered no more support than the original models.

Model of Context

This work initially focussed on competences and competence structures. Our definition of competence is a contextualised intended learning outcome. It became apparent that the underlying field concerning ILOs was underdeveloped and we directed focus there instead.

Part of the exploration of competences resulted in the creation of an original context model:

```
<context> //the things that are not the task, and yet influence the performance of the task

  <meta>
    <stereotype id=""/>
    <inherits>
      <stereotype id=""/>
    </inherits>
    <blob description=""/>
  </meta>

  <conditions>
    <external>
      <situational>

        <environmental>
          //e.g. space, lighting, noise
          <environmentalResource/>
        </environmental>
        <resource>
          <tools>
            <equipment/>
            <referenceMaterial/>
          </tools>
        </resource>
      </situational>
      <humanPhysical> //relates to humanEmotional
        //eg tired, hungry, injured, stressed
      </humanPhysical>
    </external>
    <internal>
      <resource>
        <priorKnowledge/>
      </resource>
      <humanEmotional> //relates to humanPhysical
        //eg happy, sad, overwhelmed, confident
      </humanEmotional>
    </internal>
    <artificial>
      //anything from criteria that is exposed to the student
    </artificial>
  </conditions>
</context>

<criteria> //not a part of context
  <constraints/> //eg Mandatory resource use
  <standardsOfPerformance/> //"silently"
  <timeConstriants/>
</criteria>
```

This model is in first draft and has not been developed further.

The following publications informed the model. (Zimmermann et al., 2007). (J McCarthy & Buvac, 1998), (Gilbert, 2009), (De Jong, 2007), (Brezillon, 2003).

Appendix I. ILO Network

Please see pull-out. The ILO network has been reformatted to fit page, and is therefore isomorphic to the network used in the experiments.

